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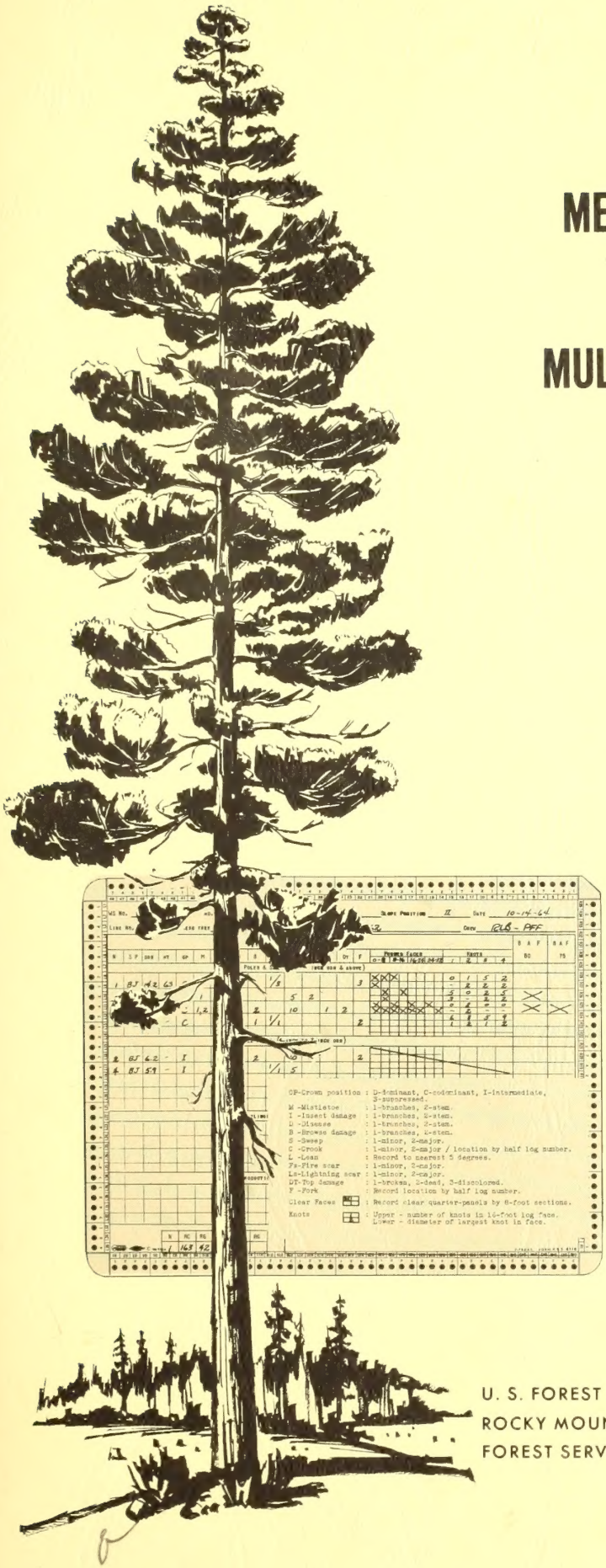
A METHOD OF EVALUATING MULTIPRODUCT POTENTIAL IN STANDING TIMBER


CP-Crown position : D-dominant, C-codominant, I-intermediate, S-suppressed.
M -Mistletoe : 1-branches, 2-stem.
I -Insect damage : 1-branches, 2-stem.
D -Disease : 1-branches, 2-stem.
B -Browse damage : 1-branches, 4-stem.
S -Sweep : 1-minor, 2-major.
C -Crook : 1-minor, 2-major / location by half log number.
L -Lean : Record to nearest 5 degrees.
Fs-Fire scar : 1-minor, 2-major.
Ls-Lightning scar : 1-minor, 2-major.
DT-Top damage : 1-broken, 2-dead, 3-discolored.
F -Fork : Record location by half log number.
Clear Faces : Record clear quarter-panels by 8-foot sections.
Knots : Upper - number of knots in 16-foot log face. Lower - diameter of largest knot in face.

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FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

FOREWORD

This paper describes and illustrates a method for evaluating multiproduct potential in standing timber. The method described will:

1. Remove observer bias from stand quality inventory.
2. Provide a record of frequency of occurrence of stem features that affect product quality and yield.
3. Characterize and quantify suitability of the timber resource for a broad range of products.
4. Provide adequate multiproduct quality and yield information for management and utilization decisions.
5. Provide a continuing basis for such decisions through time.

U. S. Forest Service Research Paper RM-15 October 1965

A METHOD OF EVALUATING MULTIPRODUCT POTENTIAL IN STANDING TIMBER

by

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and

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A Method of Evaluating

Multiproduct Potential in Standing Timber

by

Peter F. Ffolliott and Roland L. Barger

INTRODUCTION

Patterns of forest utilization are changing rapidly, with added emphasis upon new products, new conversion methods, and broader product diversification. The diversity of feasible end products makes it difficult to estimate the overall product potential of standing timber. Quality information obtained by a specific product grading system is inadequate for multiproduct appraisal.

An inventory method is needed for evaluating the suitability of standing timber over the full range of potential primary products. Such a method must evaluate standing timber in terms other than the product specifications in immediate use. Many commercial product specifications are nonuniform and incomplete, and all are subject to revision and refinement. Frequent changes in product specifications emphasize the need for basic timber quality information, divorced from specific product grading systems, but easily adapted to new or revised systems. A method of quality appraisal must consequently depend upon recognizing the fundamental stem or stand characteristics affecting wood product yields and quality. With adequate knowledge of these characteristics, it is possible to estimate present and near-future product potential for a wide variety of products.

To be effective, a method of evaluating multiproduct potential in standing timber must be easily employed with a minimum need for observer interpretation. Instead of recording a specific product grade, the quality features[2] that in general determine product grades and yield should be measured. Then, the standing timber can be appraised by applying raw-material quality standards applicable to any product.

How detailed an inventory system is must necessarily be a compromise between information desired and time and effort required to get it. A workable inventory system cannot be encumbered with detail to the extent that it becomes difficult and time consuming to apply on the ground.

The purpose of this paper is to describe a method for evaluating multiproduct potential in standing timber, and to show how data reflecting the occurrence of features that affect product quality and yield are used to estimate multiproduct potential. Measurements made in a cutover southwestern ponderosa pine stand are used to illustrate the method. The basic methodology can be extended to other types and other areas.

STUDY AREA

The study area is a 450-acre watershed on the Beaver Creek Watershed Evaluation Project in Arizona.[3] Ponderosa pine (Pinus ponderosa Laws.) comprises 85 percent of the cubic-foot volume on the area, with Gambel oak (Quercus gambelii Nutt.) and alligator juniper (Juniperus deppeana Steud.) as intermingling minor species. The soil on the area is of two soil management units, Siesta-

[2] *Quality features, as used here, are features that are correlated with suitability, yield, or both, for particular end uses.*

[3] *A 275,000-acre watershed on the Coconino National Forest in northern Arizona where costs and benefits of intensive multiple-use land management are being evaluated as a part of the Arizona Watershed Program.*

Sponseller, a "high"[4] timber producer, and Stoneman, a "medium"[4] timber producer. Timber was last cut on the study area from 1943 to 1950; one-half of the estimated merchantable volume of sawtimber was removed.

METHODS OF DATA COLLECTION

Sample Design

The method of collecting the needed data is based on point-sampling techniques. A system of point samples is placed on the ground to give a representative sample of the area, and trees are selected for measurement by using an angle gage or a prism. The occurrence of stem features that determine potential product quality and yield is then recorded for these trees.

The sample design for locating point samples may be systematic, or, if a measure of variation is desired, systematic with multiple random starts (Freese 1962, Shiue 1960).[5] If systematic sampling with multiple random starts is used, the point samples should be placed at regular intervals along lines that run across the major variation in the population. By considering each line of point samples as a sample unit, the variation will then be maximized within and minimized between sample units.

The sampling intensity will depend on (1) the variability in occurrence of the different stem features in the population, and (2) the degree of accuracy desired in sampling the features. The basal area factor (BAF) to be used in selecting individual trees for measurement will also depend on the degree of intensity desired in sampling the occurrence of stem features.

For this study, systematic sampling with multiple random starts was chosen (fig. 1). A

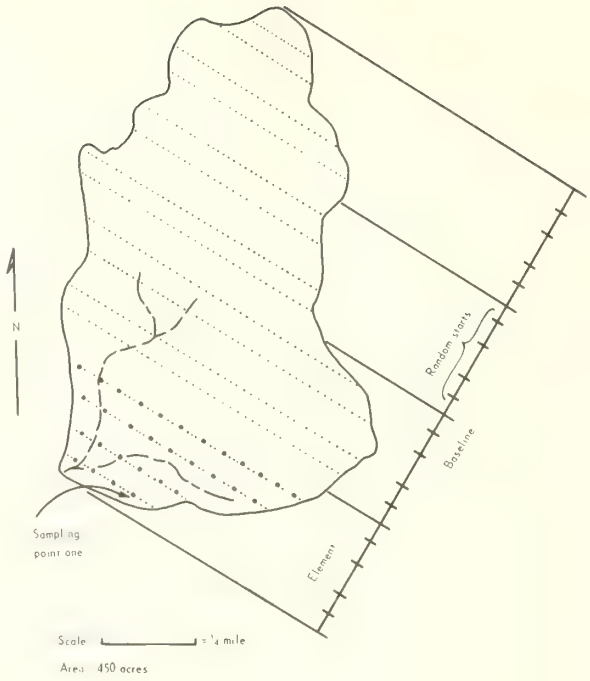

Figure 1.--The study area and illustrative systematic sampling design based on multiple random starts. Sampling points are located at uniform intervals along each random start or line.

regular interval of 3 chains (198 feet) was established between points of a system of 200 point samples. At each point sample, ponderosa pine 7.0 inches in diameter and larger were selected for measurement by using an angle gage with a basal area factor of 25.

Individual Tree Measurements

For each sample tree, selected stem features affecting product quality and quantity were measured or observed. Tree species and d.b.h. were recorded for each tree. Total height was measured from a subsample of trees sufficient to form a basis for a d.b.h.-height curve. In addition, the merchantable height of potential commercial pole stems was measured.

Other stem quality features observed can be broadly classified as (1) stem form features, (2) injury features, and (3) log knot configurations. Outlined below are the specific measurements recorded for these features.

[4] *Terms used to describe soil management area timber potentials, in Anderson, T. C., Jr., Williams, J. A., and Crezee, D. B. Soil management report for Beaver Creek Watersheds of Coconino National Forest, Region 3. 66 pp., illus. 1960. (Mimeographed report on file at Region 3 office, U. S. Forest Serv., Albuquerque, N. Mex.)*

[5] *Names and dates in parentheses refer to Literature Cited, p. 24.*

Form Features
in the Merchantable Stem

1. Feature:

   Sweep

2. Definition:

   Gradual bend in merchantable stem (fig. 2)

3. Record:

   1 if less than 1/3 d.b.h. deviation in straightness

   2 if 1/3 d.b.h. or more deviation in straightness

Figure 2.--Sweep in the merchantable stem affects suitability and yield for many end uses.

Figure 3.--Crook is a common grading and scaling defect.

1. Feature:

   Crook

2. Definition:

   Abrupt bend in merchantable stem (fig. 3)

3. Record:

   1 if less than 1/2 mean diameter deviation in straightness within a section 5 feet or less in length

   2 if 1/2 mean diameter or more deviation in straightness within section 5 feet or less in length

   NUMBER of half-log in which a crook occurs

1. Feature:

   Lean

2. Definition:

   Deviation of straight stem from vertical (fig. 4)

3. Record:

   DEGREE, to nearest 5-degree increment. Measure with plumb-bob device (Marden and Conover (1959) (fig. 5)

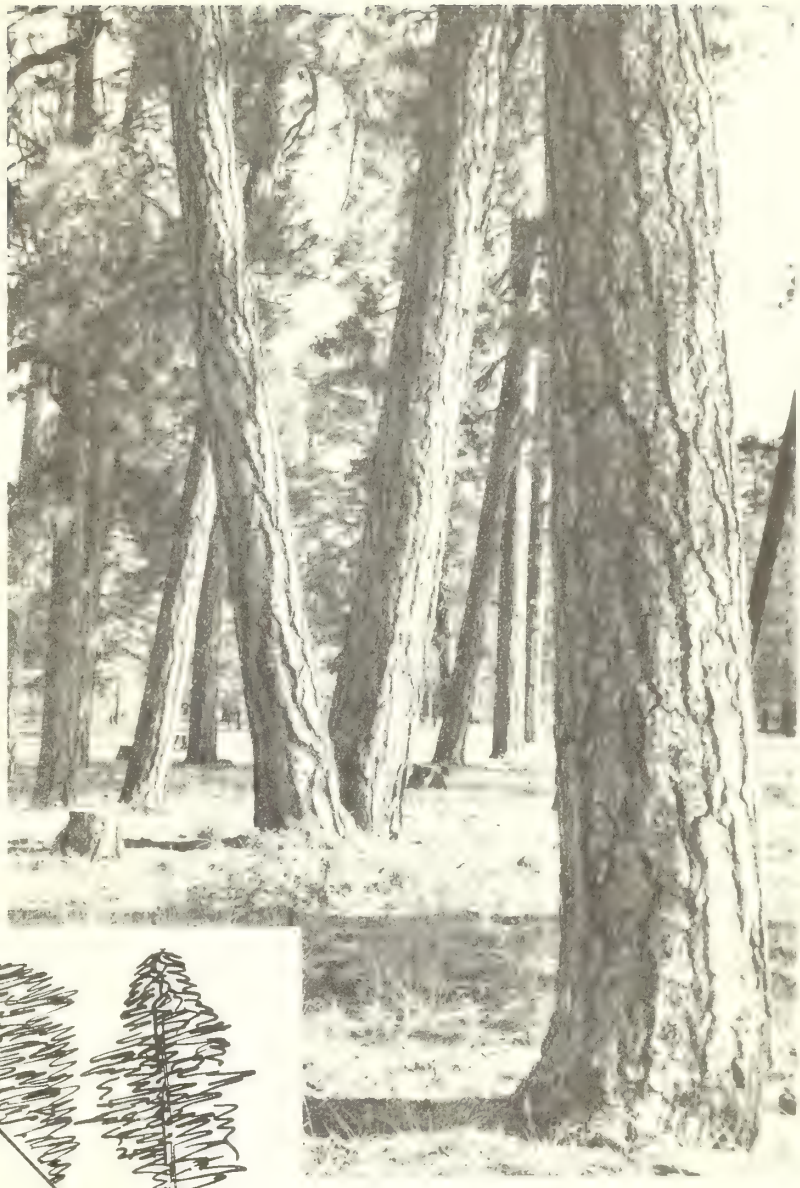

Figure 4.--Leaning stems have compression wood, a limiting defect for many end uses.

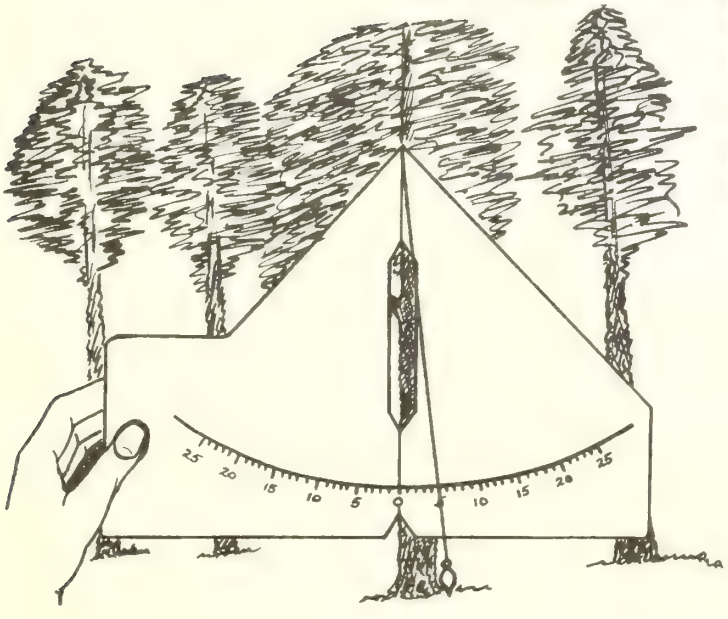

Figure 5.--A plumb-bob device was used to determine degree of stem lean.

Figure 6.--Fork in the merchantable stem affects both yield and grade.

1. Feature:

   Fork

2. Definition:

   Point of division of the merchantable stem (fig. 6)

3. Record:

   NUMBER of half-log in which fork occurs

Injury Features in the Merchantable Stem

1. Feature:

   Scar (fire, lightning, etc.)

2. Definition:

   Opening in bark exposing underlying wood (figs. 7, 8, and 9)

3. Record:

   1 if less than 1/4 circumference of stem affected

   2 if 1/4 circumference or more of stem affected

Figure 7.--Fire scars [illegible] faces of the merchantable stem.

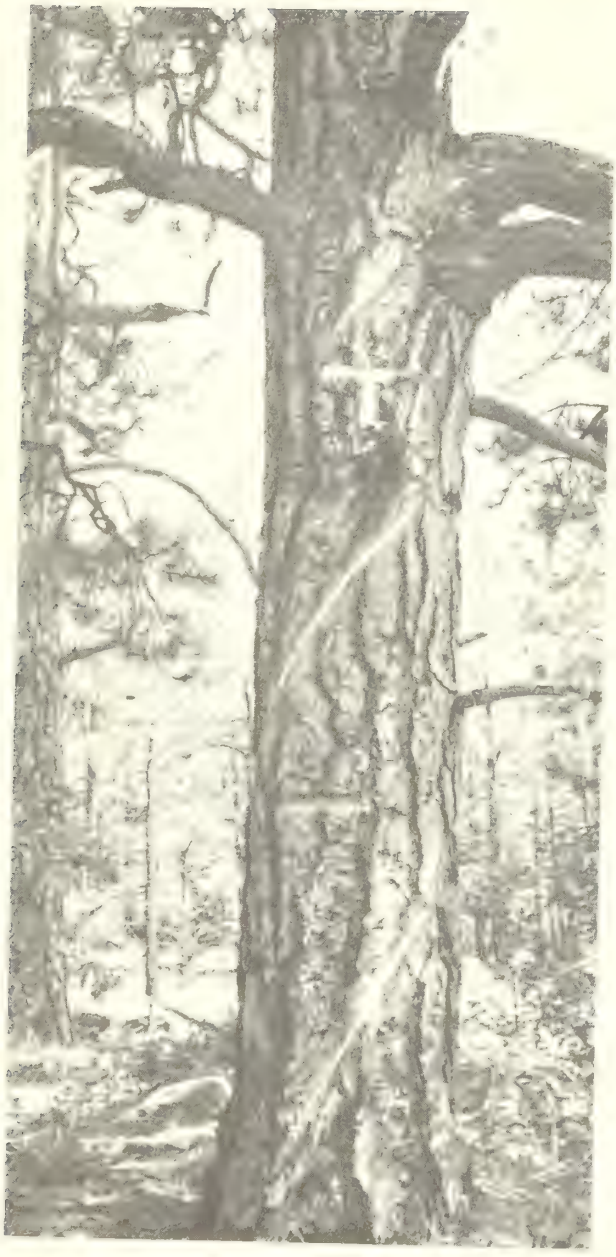

Figure 8.--Many lightning strikes cause only superficial physical damage to the merchantable stem (left). Occurrence of this type of scar was not recorded.

Figure 9.--Severe lightning scars and associated fire damage may warrant extensive grade and yield reductions (right). Occurrence of this type of scar was recorded.

1. Feature:

   Internal rot

2. Definition:

   Fungi causing partial decomposition of the merchantable stem

3. Record:

   OCCURRENCE of rot in increment borings taken from first tree tallied at each sample point (fig. 10)

Figure 10.--Full-length increment cores were removed from selected sample trees and then examined for indications of internal rot.

Log Knot Configurations in the Merchantable Stem

NOTE: Both occurrence and distribution of log knots are important indicators of product potential. Accordingly, knot features of butt logs were characterized first by occurrence of half-faces clear of knots, secondly by number and size of knots; second logs by occurrence of clear half-faces only.

1. Feature:

   Clear face

2. Definition:

   Section of stem free of log knots (fig. 11)

3. Record:

   NUMBER and POSITION of clear 8-foot half-faces in the merchantable stem (panels 8 feet × 1/4 stem circumference) selected by following procedure:

   Select a clear 8-foot half-face in butt 8-foot section of merchantable stem, and designate as face number one. If no clear half-face exists, arbitrarily select face number one.

   Record number of clear 8-foot half-faces in butt section, tallying in clockwise direction from face one.

   Record number of clear 8-foot half-faces in second 8-foot section of merchantable stem, following the same procedure, with "face one" directly alined above butt "face one."

   Follow procedure through four 8-foot sections, or to 10-inch top diameter, whichever occurs first.

   Use same designated log face positions as basis for knot count (see next page).

1. Feature:

   Log knots

2. Definition:

   Live or dead limbs, stubs, indicators, and overgrowths (Jackson 1962).

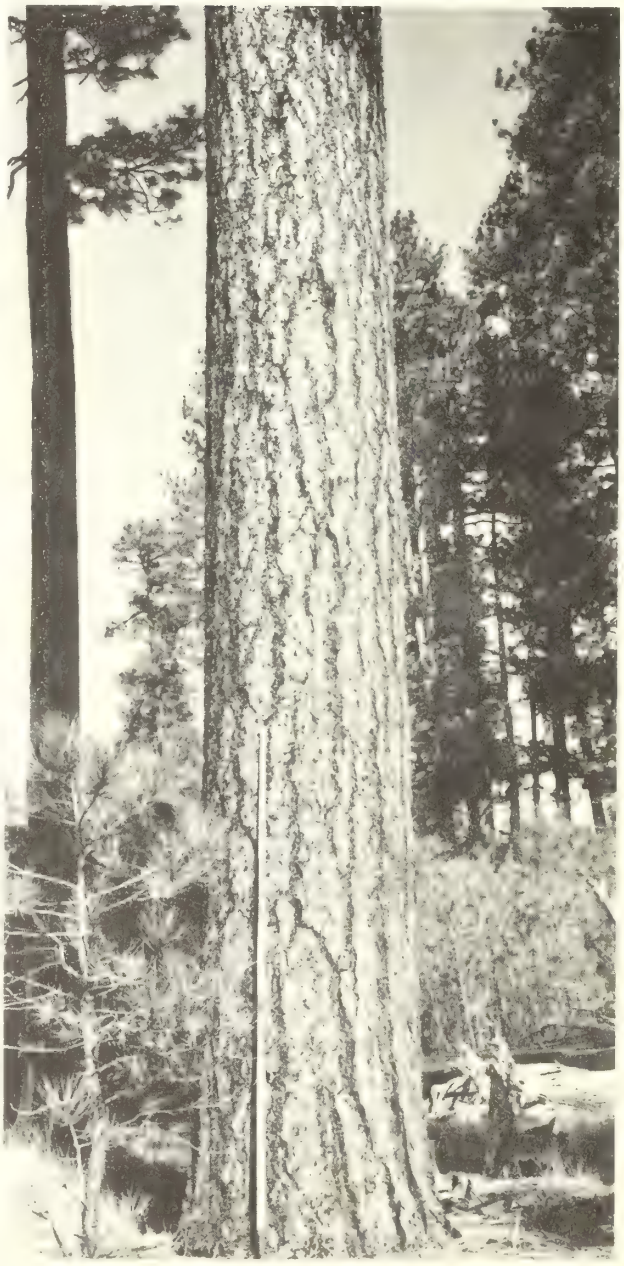

Figure 11.--Clear log faces may determine suitability for many uses.

3. Record:

For sawtimber:

NUMBER of knots in each face of butt 16-foot log.

SIZE of largest knot in each face.

For commercial poles:[6]

NUMBER of log knots in each face of full merchantable length.

SIZE of largest knot in each pole face.

The stem quality features observed are those believed most indicative of suitability and yield for a wide range of products. There are many other factors that can be important in determining material quality. Perhaps the major quality feature omitted from the described system is density, or specific gravity. Specific gravity is recognized as the best single index to the suitability of wood for several end uses; where it is of prime interest, or is subject to question, it can easily be included as an observed feature in the inventory system. Increment cores taken from selected trees at each sampling point will provide a ready basis for determining tree specific gravity averages and variation.

OCCURRENCE OF STEM QUALITY FEATURES IN A STAND

Recorded stem quality information can easily be aggregated to show the frequency of occurrence of any particular feature in the sampled stand or area, a prerequisite to further analysis of product potential for the stand. The frequency of occurrence information presented herein illustrates development of occurrence data for an area.

A stand table representative of the study area was developed from all trees tallied on the 200 point samples. Stand tables were similarly developed for trees exhibiting specific stem form or injury features. By comparing stand tables, the frequency of occurrence of specific stem features was determined.

Log knots and clear log half-faces are features potentially common to all stems, and consequently cannot be described by the stand table method. Their occurrence is instead expressed as percent of stems having specific knot size and number and/or clear half-face characteristics.

Form Features In The Merchantable Stem

Irregular form features in the merchantable stems of standing timber can substantially influence product potential. Sweep, crook, lean, and fork are particularly important determinants of volume and quality of timber for specific end uses or products (table 1).

For example, sweep reduces the usable volume of sawtimber stems, and limits the use of stems as poles. Sweep may not lower recovery from pulpwood stems, but does reduce the amount of solid wood per cord.

The suitability of standing timber for different products can be reduced as a result of crook. Crook may lower the net volume in a merchantable stem, or may be a limiting feature, as in commercial poles.

Lean is common in standing timber, and because leaning boles develop reaction wood,[7] lean is an important form characteristic. Compression wood in coniferous species is usually considered present in stems with 5 degrees of lean or more (Pillow and Luxford 1937).

[6] *Well-formed stems 9.0 to 18.9 inches in d.b.h. are considered potential commercial poles if merchantable length in feet is at least 2-1/2 times d.b.h. in inches. Merchantable length is limited by (1) length to major crown, or (2) length to single log knot 4 inches or more in diameter, or (3) length to first occurrence of knots aggregating 8 inches in diameter within a 1-foot section.*

[7] *Reaction wood is abnormal wood found in leaning stems, and is commonly referred to as compression wood in softwoods and tension wood in hardwoods.*

Table 1.--Percentage of occurrence of stem-quality features, by size classes and number of trees per acre on the study area

Stem-quality features	Size class by diameter breast height (inches)																All size classes
	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	
FORM FEATURES--	Percent																
Sweep:																	
Minor[1]	11	9	15	20	10	13	7	6	7	8	19	11	0	0	0	0	11.2
Major[2]	3	2	0	0	5	9	0	0	0	4	0	0	0	0	0	0	2.1
Total	14	11	15	20	15	22	7	6	7	12	19	11	0	0	0	0	13.3
Crook, by 8-ft. stem sections:																	
Minor[3] First	5	6	8	5	5	4	0	0	0	0	0	0	0	0	0	0	5.1
Second	3	4	0	0	5	4	4	3	0	0	0	0	0	0	0	0	2.7
Third	5	2	6	0	0	0	4	0	0	0	0	0	0	0	0	0	3.6
Fourth	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	.1
Over four	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	.1
Total	13	12	14	5	10	8	8	6	3	0	0	0	0	0	0	0	11.6
Major[4] First	1	0	4	10	0	0	0	0	0	0	0	0	0	0	0	0	1.4
Second	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Third	0	0	0	0	5	0	0	0	3	0	0	0	0	0	0	0	.2
Fourth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Over four	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	.1
Total	1	0	4	10	5	0	0	0	3	4	0	0	0	0	0	0	1.7
Total	14	12	18	15	15	8	8	6	6	4	0	0	0	0	0	0	13.3
Lean:																	
5 degrees	8	11	8	5	15	22	27	27	21	24	53	0	100	0	0	0	10.8
10 degrees	1	0	0	5	20	6	4	9	10	4	9	0	0	0	0	0	2.2
15 degrees	0	0	0	0	0	0	7	3	0	4	9	0	0	0	0	0	.4
20 degrees	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	.3
Total	9	11	10	10	35	28	38	39	31	32	71	0	100	0	0	0	13.7
Fork, by 8-ft. stem sections:																	
First	3	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1.5
Second	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	.1
Third	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	.1
Fourth	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	.1
Fifth	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	.1
Sixth	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	.1
Seventh	0	0	0	0	0	0	4	0	0	4	0	0	0	0	0	0	.1
Total	3	0	0	0	5	6	12	0	0	8	0	0	0	0	0	0	2.1
INJURY FEATURES--																	
Fire scar:																	
Minor[5]	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0	67	.2
Major[6]	0	0	0	0	0	3	0	0	3	0	0	11	0	50	0	0	.2
Total	0	0	0	0	0	3	4	3	3	0	0	11	0	50	0	67	.4
Lightning scar:																	
Minor[5]	0	0	0	0	0	0	4	6	3	4	19	0	0	0	0	0	.5
Major[6]	0	0	0	0	0	3	7	6	10	12	9	11	0	50	0	67	1.0
Total	0	0	0	0	0	3	11	12	13	16	28	11	0	50	0	67	1.5
	Number																
TREES PER ACRE --	28.2	12.4	7.62	2.36	1.80	2.25	1.48	1.61	1.16	0.82	0.32	0.18	0.02	0.04	0.02	0.03	60.31

[1] Less than one-third d.b.h. deviation in straightness.
[2] At least one-third d.b.h. deviation in straightness.
[3] Less than one-half mean diameter deviation in straightness within section 5 feet or less in length.
[4] At least one-half mean diameter deviation in straightness within section 5 feet or less in length.
[5] Affecting less than one-fourth merchantable stem circumference.
[6] Affecting at least one-fourth merchantable stem circumference.

Forking in the merchantable stem limits the length or net scale of products obtained. The distorted grain accompanying a fork may also lower the quality of adjacent material.

Injury Features In The Merchantable Stem

The presence of mechanical injuries such as fire and lightning scars [8] (table 1) can reduce substantially the usable volume of standing timber. Injury scars are also recognized as secondary grading defects in determining timber quality for various products.

Internal rot in the merchantable stem is often the greatest single cause of biological injury in a forest (Pearson 1950). Internal rot can greatly reduce the yield of material suitable for different products.

Evidence of heart rot in increment cores should be used as an index of occurrence and not necessarily as an absolute measure of incidence and cull volume. Heart rot [9] was ob-

[8] *Occurrence of superficial lightning scars was not recorded; only those sufficiently severe to affect the yield and/or grade of material were recorded (see figs. 8 and 9).*

[9] *Polyporus anceps Pk. (P. ellisianus (Murr.) Sacc. & Trott.) is common heart rot in ponderosa pine in the Southwest (Andrews 1955).*

Table 2.--Occurrence of clear half-faces[1] in the first two 8-foot stem sections[2] and of log knots in the butt 16-foot logs of the sawtimber on the study area

Configurations in merchantable stem	Size class by diameter breast height (inches)														All size classes
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	
	Percent of stems														
Clear half-faces in first and second 8-foot sections:															
None --															
First	100	95	74	80	68	68	75	68	73	50	50	0	0	50	77.5
Second	100	100	90	94	80	88	100	84	91	100	100	100	100	0	92.1
One --															
First	0	0	21	10	20	26	14	16	27	50	50	100	0	0	15.0
Second	0	0	10	3	20	6	0	12	9	0	0	0	0	100	6.3
Two, opposite --															
First	0	0	5	3	0	3	4	4	0	0	0	0	0	50	2.4
Second	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Two or more; adjacent --															
First	0	5	0	7	12	3	7	12	0	0	0	0	100	0	5.1
Second	0	0	0	3	0	6	0	4	0	0	0	0	0	0	1.6
Log knots in butt 16-foot logs:															
Number --															
0 - 10	0	0	0	10	4	15	3	0	9	33	0	50	0	50	5.9
11 - 20	8	5	26	10	36	21	29	56	28	17	50	50	0	50	23.3
21 - 30	17	25	42	53	28	32	39	20	45	33	50	0	0	0	30.4
Over 30	75	70	32	27	32	32	29	24	18	17	0	0	100	0	40.4
Size of largest knot --															
1 - 2 inches	33	35	26	20	12	12	3	12	0	17	0	0	0	0	18.2
3 - 4 inches	65	55	63	64	64	53	68	60	36	17	50	50	0	100	59.6
5 - 6 inches	2	5	11	13	24	32	29	28	36	66	50	50	0	0	19.8
Over 6 inches	0	5	0	3	0	3	0	0	28	0	0	0	100	0	2.4
	Number														
Trees on study area	48	20	19	30	25	34	28	25	11	6	2	2	1	2	253

[1] Log surface one-fourth the circumference of the log and 8 feet in length.
[2] Occurrence of clear 8-foot half-faces was recorded for entire merchantable stem; data are not presented for stem sections above 16 feet, since they contained less than 2 percent of all clear-half-faces recorded.

served in 7 of 148 increment borings (4.7 percent) taken in ponderosa pine 8 inches d.b.h. and larger on the study area.

Log Knot Configurations In The Merchantable Stem

Data on distribution of clear 8-foot half-faces and the number and size of log knots by tree size classes within the stand will allow an evaluation of standing timber potential for a variety of products.

Data on clear 8-foot half-faces, given in table 2, are for only the first two 8-foot stem sections, since they contained more than 98 percent of all clear half-faces recorded.

The occurrence and size of log knots in the butt 16-foot log are shown in table 2. The same data would be shown to describe the occurrence and size of log knots in potential poles if stems meeting commercial requirements (see footnote 6) were available.

INTERPRETATION OF STEM QUALITY INFORMATION

The recorded stem-quality data have wide potential application in characterizing either a stem or a stand. The data allow a wide range of interpretive precision, depending upon the nature of quality information desired. Many management and utilization decisions can be based upon a broad analysis of the quality and product potential of a stand. This type of analysis may require only consideration of certain stem quality features in the aggregate; that is, in terms of frequency of occurrence in the stand as a whole. Conversely particular utilization decisions may require a quite detailed analysis of stem features in specific size or form classes. Finally, detailed inquiries may warrant diagraming individual sample stems. The degree of precision in interpretation can be tailored somewhat to meet the needs at hand.

The wide range of stem quality information afforded by the data is best illustrated through schematic diagraming techniques. The butt logs of the first four trees recorded in figure 12 are diagramed in figures 13 through 16. In addition, the full merchantable pole length of tree number 4 is diagramed in figure 16.

As is apparent in the preceding diagrams, rather definite quality inferences for a variety of products can be drawn from the stem quality data. Such quality information for a

Point No 1 Aspect W Date 7-20-63
Slope Posit Intermed. Slope Percent 5 Crew PF-RB

No	SP	DBH	HT	S	C	L	Fs	Ls	F	Clear faces 8	16	24	32	Knots 1	2	3	4
Large Poles & Sawtimber (8" DBH and over)																	
1	PP	21.3	63			5	2			X	X	+	+	0	6	9	2
														–	3	3	2
2	PP	18.2			1/1	5			2	X	+	+	+	9	17	12	14
														2	2	3	2
3	PP	35.8		2		10	1			X	X	+	+	3	8	5	7
														4	4	6	5
4	PP	13.8			1/3					+	+	+	+	9	11	12	10
														2	1	2	1
" (AS POLE)	"	"	POLE AT 35'		1/3					+	+	+	+	17	23	21	18
														2	2	3	2
Small Poles (4 to 7-inch DBH)																	
5	PP	6.2		2		10			2								
6	PP	5.9			1/1	5											

Figure 12.--Sample tally card for a single sampling point, indicating manner in which stem quality information was recorded.

Key to recorded stem features:

S - Sweep : 1 indicates minor, 2 indicates major
C Crook : 1 above slash indicates minor, 2 indicates major, number below slash indicates half-log height in tree.
L - Lean : Recorded in degrees, to the nearest 5-degree increment.
Fs Fire scar : 1 indicates minor, 2 indicates major.
Ls Lightning scar : 1 indicates minor, 2 indicates major.
F - Fork : Number indicates half-log height of occurrence in tree
Clear Faces : Occurrence of 8-foot clear panels indicated by position on stem, for first 32 feet of merchantable height.
Knots : For each face of butt 16-foot log, upper number indicates total knots in face, lower number indicates diameter of largest knot

RECORDED QUALITY FEATURES FROM THE INVENTORY RECORD CARD, SUCH AS:

N	SP	DBH	S	C	L	Fs	Ls	F	CLEAR FACES 8	16	24	32	KNOTS 1	2	3	4
1	PP	21.3			5	2			X	X			0	6	9	2
													-	3	3	2

CAN BE DIAGRAMED AS:

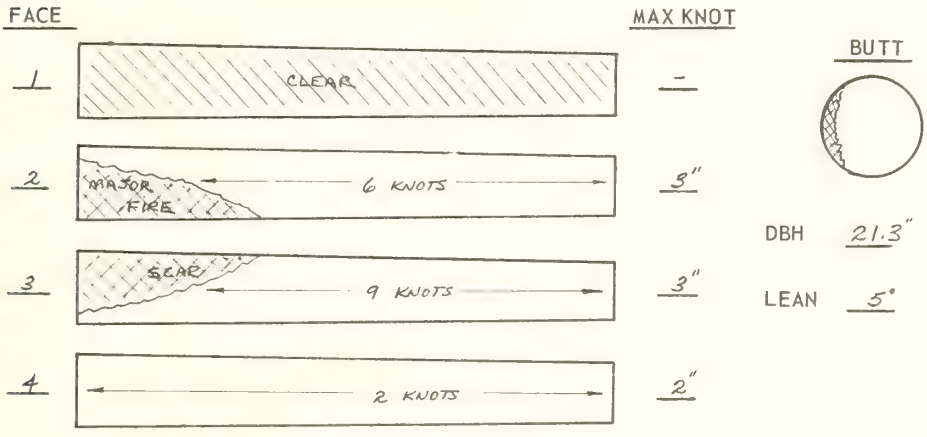

Figure 14.--Schematic diagram of features of the butt 16-foot log--tree number 1.

RECORDED QUALITY FEATURES FROM THE INVENTORY RECORD CARD, SUCH AS:

N	SP	DBH	S	C	L	Fs	Ls	F	CLEAR FACES 8	16	24	32	KNOTS 1	2	3	4
2	PP	18.2		1/1	5			2	X				9	17	12	14
													2	2	3	2

CAN BE DIAGRAMED AS:

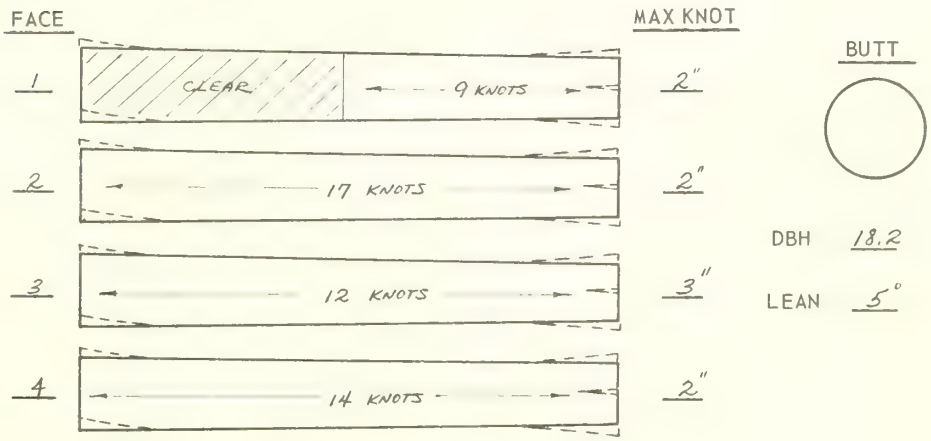

Figure 14.--Schematic diagram of features of the butt 16-foot log--tree number 2.

RECORDED QUALITY FEATURES FROM THE INVENTORY CARD, SUCH AS:

N	SP	DBH		S	C	L	Fs	Ls		F	CLEAR FACES 8	16	24	32	KNOTS 1	2	3	4
3	PP	35.8		2		10	1				X	X			3	8	5	7
															4	4	6	5

CAN BE DIAGRAMED AS:

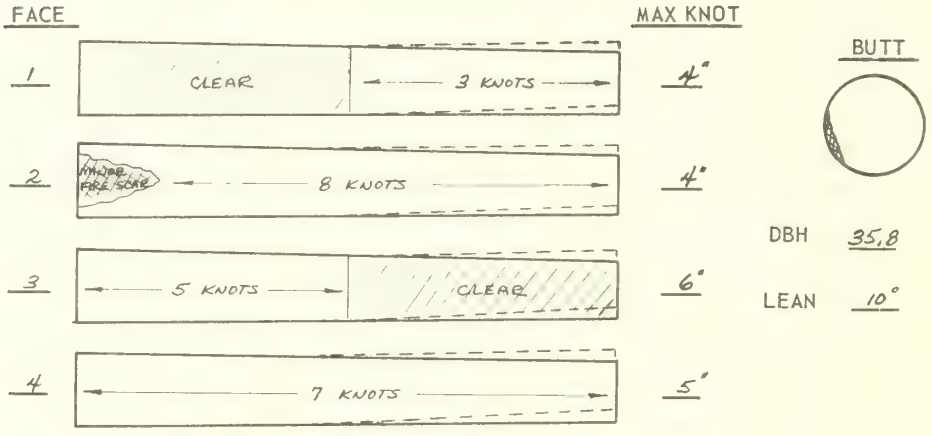

Figure 15.--Schematic diagram of features of the butt 16-foot log--tree number 3.

RECORDED QUALITY FEATURES FROM STEMS HAVING APPARENT POTENTIAL FOR COMMERCIAL POLES, SUCH AS:

N	SP	DBH	HT		S	C	L	Fs	Ls		F	CLEAR FACES 8	16	24	32	KNOTS 1	2	3	4
4	PP	13.8	52			1/3						+	+	+	+	9	11	12	10
																2	1	2	1
"	"	"	POLE HT. 35			"						+	+	+	+	17	23	21	18
(AS POLE)																2	2	3	2

WILL PERMIT DIAGRAMING FULL POTENTIAL POLE LENGTH, AS:

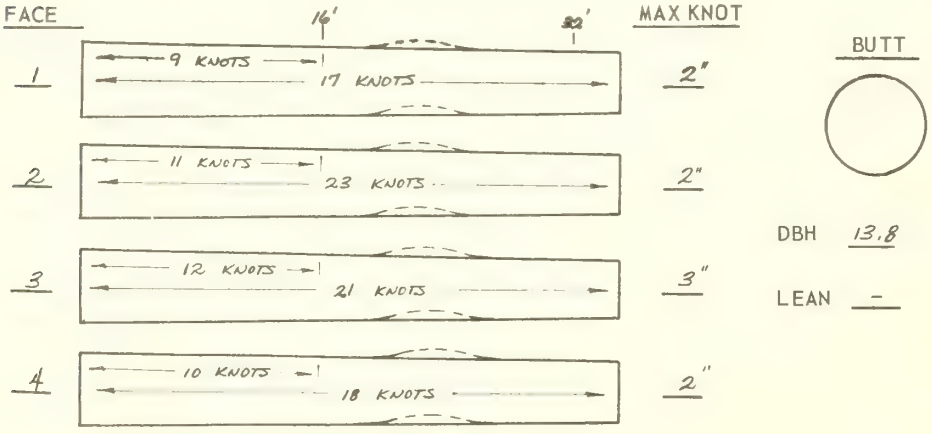

Figure 16.--Schematic diagram of features of the butt 16-foot log, and merchantable pole length, of tree number 4.

stand provides the basis for appraising and comparing potential for products considered either now or later. The range of products under consideration will vary somewhat with the locale and nature of the timber.

MULTIPRODUCT POTENTIAL--AN EXAMPLE

The inventory system described provides a means of appraising the potential of a timber stand for a range of products. Gross and net volumes of raw material, by size class, can be determined. The extent and impact of particular types of visible defect important to specific products can be appraised. More important, the material can be stratified into quality classes or grades appropriate for the products considered. The following analysis of multiproduct potential on the study area is presented as an example of application of the system to a specific timber stand.

For the locale and the timber under study, four primary products were considered: saw logs, veneer logs, commercial poles, and pulpwood. Although local markets are not currently active for all these products, their development in the foreseeable future seems imminent. The manner in which recorded quality data can be applied in appraising product potential is amply demonstrated by this group of products.

Saw Log Potential

Gross Volume Determination

All timber in diameter classes 12 inches and larger was considered potential sawtimber. Gross volume, by diameter class, was obtained by applying localized board-foot Scribner scale volume tables (Myers 1963) to stand measurement data. A high proportion of the merchantable volume of sawtimber was found in butt 16-foot logs. All diameter classes averaged less than two full logs in merchantable height. The gross volume in each diameter class, and the proportion of volume by log position, are shown in table 3.

Table 3.--Gross volume,[1] deductions by defect type, and net volume[2] of saw logs by tree diameter class

D.b.h. class (Inches)	Gross saw-log volume					Deduction by defect type							Net saw-log volume				
	Per acre	Distribution by log position				Fire scar	Lightning scar	Fork	Crook	Minor sweep[3]	Major sweep[4]	Total defect	Per acre	Quality distribution by grade[5]			
		Butt log		Second log										3 and better		4 and 5	
	Bd.ft.	Bd.ft.	Pct.	Bd.ft.	Pct.	---------- Percent ----------							Bd.ft.	Bd.ft.	Pct.	Bd.ft.	Pct.
12	213	[illegible]	100	0	0	0	0	0	3.0	3.0	0	6.0	200	4	2	196	98
14	187	187	100	[illegible]	0	0	0	0	3.7	4.0	0	7.7	173	9	[illegible]	164	95
16	203	168	83	35	17	0	0	.2	[illegible]	2.0	2.5	7.0	189	26	14	163	86
18	391	301	77	90	23	.2	1.5	1.2	1.5	2.6	4.5	11.5	346	24	7	322	93
20	451	316	70	135	30	0	4.5	[illegible]	1.0	1.4	0	7.2	419	84	20	335	80
22	612	416	68	196	32	0	4.5	0	.8	1.2	0	6.5	572	103	18	469	82
24	576	369	64	207	36	.2	5.8	0	.3	1.4	0	7.7	532	64	12	468	88
26	374	239	64	135	36	0	7.0	0	0	1.6	2.0	10.6	334	57	17	277	83
28	441	282	64	159	36	0	9.3	0	0	3.8	0	13.1	383	46	12	337	88
30	136	87	64	49	36	.6	[illegible]	0	0	2.2	0	8.3	125	27	22	98	78
32	59	37	62	22	38	0	0	0	0	0	0	0	59	19	33	40	67
34	34	21	62	13	38	2.6	25.0	0	0	0	0	27.6	25	17	67	8	33
36	26	16	60	10	40	0	0	0	0	0	0	0	26	17	67	9	33
38	42	27	64	15	36	0	33.3	0	0	0	0	33.3	28	19	67	9	33
All size classes	3,745	[illegible]	72	1,066	28	.1	4.9	.2	.9	[illegible]	.8	8.9	3,411	516	15	2,895	85

[1] Basis: Myers (1963).
[2] Exclusive of volume deduction due to internal defect.
[3] Less than one-third d.b.h. deviation in straightness.
[4] At least one-third d.b.h. deviation in straightness.
[5] Basis: Gaines (1962).

Net Volume Determination

Determining net volume of raw material for a particular product depends upon knowing (1) what stem features will reduce usable volume, (2) the frequency of occurrence of these features in a stand, and (3) the effect of these defect features upon the volume of a right cylinder or scaling cylinder.

For the stand considered, internal rot, scar, sweep, crook, and fork are stem features that may potentially reduce usable saw-log volume. Internal rot cannot be adequately evaluated in standing timber, except in terms of historical scaling data from similar stands. All other stem features mentioned are visible in standing timber, however, and can be evaluated. The frequency of occurrence of these features in the stand is known. The effect of a particular type of defect upon the volume of a right cylinder can be estimated. Frequency of occurrence data for a feature, when combined with estimated effect upon right cylinder volume, provides an index of scale deduction for that feature.

Theoretical determination of the effect of a particular type of defect upon scaling volume is subject to error. It should be noted, however, that only the effect of the defect upon volume of a right cylinder is estimated. This purely geometrical relationship can then be applied to known gross scale and known frequency of occurrence to calculate actual scaling deduction. This procedure should prove substantially more accurate than the common tree measurement scaling practice of applying a single predetermined cull factor to gross scale. In addition, a specific scale deduction by type of defect, for each diameter class, is estimated. This type of information is valuable as a further basis for utilization and management decisions.

Log diagrams and standard scaling procedures were used in determining the extent to which specific types of defect impinged upon the right cylinder. The scale-deduction factors used for visible defect were:

Scars--

Fire scars

Minor fire scar--disregarded due to containment in the portion of stem lying outside a right cylinder.

Major fire scar--deduct 1/3 of lower 4 feet of the scaling cylinder; i.e.,1/12 of butt log gross scale.

Lightning scars

Minor lightning scar--deduct 1/4 of gross scale of entire merchantable stem.

Major lightning scar--deduct 1/2 of gross scale of entire merchantable stem.

Fork--Deduct 1/4 of gross scale of the 16-foot log in which fork occurs.

Crook--Deduct 1/4 of gross scale of the log in which crook occurs.

Sweep[10]--

Minor sweep--deduct 1/5 of gross scale of entire merchantable stem.

Major sweep--deduct 1/2 of gross scale of entire merchantable stem.

In each diameter class, frequency of occurrence data were applied to gross scale, by log position, to obtain the actual volumes of timber affected by a particular defect. The appropriate scale deduction factor was then applied to the affected volume to determine board-foot scale deduction. Scaling deductions for each type of visible defect, by tree diameter classes, are shown in table 3. The resulting net volumes, exclusive of internal defect deductions, are also shown.

Saw-Log Quality Determination

In appraising saw-log quality potential, it is usually desirable to estimate log-grade distribution by the particular grading system currently recognized for the species. Saw-log grading systems are generally based upon the size, number, and distribution of log knots, the presence of clear surface area, and the occurrence of certain form and injury "secondary" defect. From the quality data reflecting the occurrence of these features,

[10] *Deductions for minor and major sweep are based upon sweep equal to 1/3 d.b.h. and full d.b.h., respectively, in 2-log trees.*

probable log-grade distribution in the stand can be ascertained with a high degree of confidence. Stratification into individual grades is not always necessary. For many utilization and management decisions, knowledge that a certain proportion of a stand of sawtimber will run "Grade 3 and better" and a remaining proportion "Grade 4 and lower" is invaluable. This type of information, as well as more detailed probable grade distribution, is readily obtained from the stem quality data.

The improved 5-grade log-grading system (Gaines 1962) is currently recognized for ponderosa pine. Accordingly, net saw-log volume was stratified by interpreting recorded stem quality data in terms of these specific grading rules. It was immediately apparent that the saw-log potential of the stand consisted primarily of Grade 5 material, with a small proportion of Grade 3 and better. In view of the inherently low quality spread, saw-log quality stratification into "Grade 3 and better" and "Grade 4 and lower" classes, by tree diameter class, appeared to be sufficiently detailed for practical purposes.

Logs were stratified into the two log-quality classes by applying the following grading criteria to recorded stem quality data:[11]

Butt logs--

Grade 3 and better indicated by

Presence of 6 or more clear 4-foot surface panels.

Presence of 4 or 5 clear 4-foot surface panels, plus total of less than 25 log knots.

Presence of 2 or 3 clear 4-foot surface panels, plus total of less than 15 log knots.

Remainder of butt logs considered Grade 4 or lower.

Second logs--Graded solely on the basis of presence or absence of clear surface area, adjusted for length of log.

[11] *To fit this particular grading system, presence of assured clear 4-foot panels may be indicated by recorded 8-foot clear half-faces (two panels), and by number of knots in a log face. For example, 2 log knots in a 16-foot log face assure at least 1 clear 4-foot panel.*

Net saw-log potential per acre, by log quality class and tree diameter class, is presented in table 3.

Veneer Log Potential

Gross Volume Determination

Gross veneer log potential, expressed in board feet Scribner scale, was considered equivalent to previously determined saw-log gross volume in the stand. Any stem of saw-log size is potentially veneer stock for sheathing-grade softwood plywood. Gross veneer log volume in each diameter class, and proportion of volume by bolt position, is shown in table 4.

Net Volume Determination

Visible stem features that reduce usable veneer log volume differ somewhat from those affecting saw-log volume. They include scar, fork, crook, and lean. Most sweep can be eliminated in bucking to veneer-bolt lengths. For scar, fork, and crook, the scale deduction factors previously developed for saw logs were used. Because the compression wood found in leaning stems can seriously limit the manufacture of veneer, stems with a lean of 10 degrees or more were culled, and 100 percent of their volume deducted from gross volume. Net veneer log scale was obtained by applying these scale deduction factors in the manner previously discussed. Veneer log scale deductions for each type of visible defect, by tree diameter class, are shown in table 4. Net volumes, exclusive of deduction for internal defect, are also shown.

Veneer Log Quality Determination

Well-defined quality standards do not exist for ponderosa pine veneer logs, yet some knowledge of the suitability of the timber for veneer is absolutely necessary for a rational appraisal of plywood opportunities. Quality standards that are developed for veneer logs will undoubtedly use as primary grading criteria some of the stem features included in this inventory system. Veneer recovery stud-

Table 4.--Gross volume,[1] deductions by defect type, and net volume[2] of veneer logs by tree diameter class

D.b.h. class (Inches)	Gross veneer log volume				Deduction by defect type						Net veneer log volume						
	Per acre	Distribution by veneer bolt position			Fire scar	Lightning scar	Fork	Crook	Lean (10° or more)	Total defect	Per acre	Veneer log distribution by quality class[4]					
		First	Second	Third								Quality 1		Quality 2		Quality 3	
	Bd.ft.	--	Percent	--	------			Percent		- ---	Bd.ft.	Bd.ft.	Pct.	Bd.ft.	Pct.	Bd.ft.	Pct.
12	213	60	40	0	0	0	0	3.0	2.0	5.0	202	0	0	0	0	202	100
14	187	59	41	0	0	0	0	3.7	5.0	8.7	171	3	2	0	0	168	98
16	203	47	33	20	0	0	.2	2.3	20.0	22.5	157	0	0	19	12	138	88
18	391	43	34	23	.2	1.5	1.2	1.5	6.0	10.4	350	14	4	18	5	318	91
20	451	43	32	25	0	4.5	.3	1.0	11.0	16.8	375	15	4	60	16	300	80
22	612	42	33	25	0	4.5	0	.8	12.0	17.3	506	15	3	71	14	420	83
24	576	41	33	26	.2	5.8	0	.3	10.0	16.3	482	10	2	29	6	443	92
26	374	40	33	27	0	7.0	0	0	8.0	15.0	318	16	5	41	13	261	82
28	441	39	33	28	0	9.3	0	0	18.0	27.3	321	0	0	39	12	282	88
30	136	38	34	28	.6	5.5	0	0	0	6.1	128	0	0	22	17	106	83
32	59	38	33	29	0	0	0	0	0	0	59	0	0	10	17	49	83
34	34	37	34	29	2.6	25.0	0	0	0	27.6	25	0	0	8	33	17	67
36	26	37	33	30	0	0	0	0	0	0	26	9	33	0	0	17	67
38	42	38	33	29	0	33.3	0	0	0	33.3	28	0	0	5	17	23	83
All size classes	3,745	43	34	23	.1	4.9	.2	.9	9.8	15.9	3,148	82	3	322	10	2,744	87

[1] Basis: Myers (1963).
[2] Exclusive of volume reduction due to internal defect.
[3] Basis: nominal 8-foot veneer bolt length.
[4] Basis: veneer bolt quality classes assumed in the study.

ies have indicated that clear bolt faces, and particularly adjacent clear faces, are probably the best single indicator of veneer recovery potential. A significant quality grading system might then be based upon the occurrence and relative position of clear bolt faces. Accordingly, three veneer bolt quality classes based on these criteria were hypothesized for 8-foot veneer bolts:

Class 1--two or more adjacent clear bolt faces (8-foot half-faces).
Class 2--one clear bolt face, or two opposite clear bolt faces.
Class 3--no clear bolt faces.

Recorded stem quality data indicating the occurrence and position of 8-foot clear faces provide the means of segregating material into these quality classes. Net veneer log potential per acre, by bolt quality class and tree diameter class, is presented in table 4.

Commercial Pole Potential

Gross Pole Potential

Stems that meet pole specifications have a value as poles that far exceeds their value in alternative uses. Consequently, pole potential for the example stand was appraised carefully. Gross commercial pole potential for a stand is expressed in terms of stems per acre, rather than volumetric measurement. All stems 9.0 to 18.9 inches in diameter were initially considered potential poles. Gross pole potential by tree diameter class is indicated in table 5.

Net Pole Potential

Due to the stringent specifications for commercial poles, a number of visible stem features render stems unsuitable: excessive knot size, excessive aggregations of knots, compression wood (lean), fork, crook, and major sweep. In general, poles with a single knot greater than 4 inches in diameter, or knots aggregating over 8 inches in diameter within a 1-foot stem section, are inadmissible. These limiting knot features were used in the field as an indication of maximum merchantable pole length. Only stems with an apparent merchantable pole height in feet of at least 2-1/2 times diameter in inches could be designated for further consideration. As shown in table 5, knot limitations eliminated all potential poles. The remaining limiting stem features, including fork, crook, major sweep, and lean of 5 degrees or more, were still evaluated, however, to complete the sample analysis of net pole potential. The additional reductions in net pole potential that would be imposed by these remaining limiting stem

Table 5.--Gross pole potential, reductions due to limiting features, and net potential, by tree diameter class

D.b.h. class (Inches)	Gross poles per acre	Limiting stem features					Total reduction[5]	Net poles[6] per acre
		Inadmissible knot features[1]	Fork	Crook[2]	Major sweep[3]	Lean[4]		
	Number	Percent						Number
10	12.40	100	0	0	2	11	100	0
12	7.62	100	0	4	0	10	100	0
14	2.36	100	0	10	0	10	100	0
16	1.80	100	5	5	5	35	100	0
18	2.25	100	6	0	9	28	100	0
Total	26.43	100.0	.9	2.4	2.0	13.7	100.0	0

[1] Knot features were considered inadmissible if a single 4-inch diameter knot, or knots aggregating 8 inches in diameter within a 1-foot stem section, limited merchantable length in feet to less than 2-1/2 times d.b.h. in inches.
[2] At least one-half mean diameter deviation in straightness within section 5 feet or less in length.
[3] At least one-third d.b.h. deviation in straightness.
[4] 5 degrees or more.
[5] Aggregate percent reductions in each diameter class will exceed 100 percent, due to multiple occurrence of limiting stem features.
[6] Exclusive of reductions due to internal defect.

features are also shown in table 5. It should be noted that aggregate reductions in all diameter classes exceed 100 percent due to the multiple occurrence of limiting features.

Commercial Pole Quality Segregation

Quality standards for commercial poles are defined in specifications set forth by the American Standards Association (1963). Because of critical strength requirements, the quality standards are detailed and stringent. The pole potential of a stand is consequently quite easily overestimated. "Apparent" pole potential based upon stem size distribution is particularly misleading, as is demonstrated by the foregoing analysis of net potential. A valid appraisal requires knowledge of the frequency of occurrence of limiting stem features. The recorded stem quality data provide the means of making such an appraisal.

Once net pole potential is determined, the recorded information also provides a means of segregating by quality classes or potential value classes. Recognized classes of commercial poles are based upon pole length and diameter, both of which are known from inventory data. For timber stands in which a net pole potential is found, this potential can be expressed in terms of commercial pole class distribution. Again, for particular applications, a less detailed quality stratification may be more desirable, such as height classes of "under 40 feet" and "over 40 feet." This also is readily obtained from inventory data.

Potential pole stems may find use in construction, as well as for transmission poles. Pole frame construction accounts for a considerable proportion of the market for shorter poles. Standard specifications, other than those developed to meet particular design requirements, do not exist for construction poles. The Forest Products Laboratory has recommended, however, that poles used for framing meet American Standard or equivalent grades (Wood 1957). Because poles commonly used in construction are shorter than transmission poles, the minimum height-diameter ratio relationship of 2-1/2 times diameter can be reduced substantially. It should be noted, however, that inventory data do provide for appraising pole potential by any specific quality criteria judged suitable for the end use in mind.

Pulpwood Potential

Gross Volume Determination

Depending upon demand for pulpwood and the nature of future multiproduct logging operations, virtually all of the timber considered might be utilized as pulp. Consequently, all timber 7.0 inches and larger in diameter was considered potential pulpwood. Since the inventory data provide volume in-

formation by tree diameter classes, the volume in any range of diameter classes under consideration is immediately available. Gross pulpwood volumes were obtained by applying localized cubic-foot volume tables (Myers 1963) to stand measurement data. Gross pulpwood volume, by tree diameter class, is indicated in table 6.

Net Volume Determination

Most visible stem quality features will not significantly affect volume of usable pulpwood. Fire scar, however, will affect net volume both as an absolute reduction of volume and as a source of charred, unsuitable material. Because charred wood must be excluded from pulping operations, fire scarred trees probably will be long-butted above the scar. Consequently, a cubic-foot volume deduction equivalent to the lower 4 feet of the merchantable stem was adopted. Lightning scars of the type recorded are similarly often accompanied by charred wood, pitch streaks, and ingrown callus bark. Stems with lightning scar were therefore considered unsuitable for pulp, and were culled from gross scale. These scale deduction factors were applied to the proportion of the stand affected by fire and lightning scar. Resulting scale deductions and net pulpwood volumes, by tree diameter class, are shown in table 6.

Table 6.--Gross pulpwood volume,[1] deduction due to defect, and net volume,[2] by tree diameter class

D.b.h. class (Inches)	Gross volume per acre	Defect type		Total defect	Net volume per acre
		Lightning scar	Fire scar		
	Cu.ft.	- - - Percent - - -			Cu.ft.
8	94	0	0	0	94
10	87	0	0	0	87
12	66	0	0	0	66
14	51	0	0	0	51
16	50	0	0	0	50
18	89	3	.6	3.6	86
20	96	11	.6	11.6	85
22	118	12	.5	12.5	103
24	104	13	.4	13.4	90
26	67	16	0	16.0	56
28	74	28	0	28.0	53
30	22	11	1.9	12.9	19
32	9	0	0	0	9
34	5	50	10.2	60.2	2
36	4	0	0	0	4
38	6	67	11.0	78.0	1
All size classes	942	8.6	.4	9.0	856

[1] Basis: Myers (1963).
[2] Exclusive of volume deduction due to internal defect.

Pulpwood Quality Segregation

Specific, well-defined quality criteria have not been developed for raw pulpwood. Certain quality specifications are often used by pulpmills, however, in defining the type of material they are willing to accept. It seems probable that, in the future, more attention will be given to defining quality classes for such material. It is not difficult to visualize stem characteristics that might reduce its suitability for pulpwood. For example, severe crook, sweep, or fork may make handling difficult, reduce the solid wood volume of a load, and interfere with debarking or mechanical grinding. Compression wood, indicated by lean, may significantly reduce pulp yields. The cellulose content of severe compression wood has been found to be as much as 50 percent below normal (Hale et al. 1961). Excessive numbers of large knots may reduce suitability of pulpwood for grinding and reduce value for chemical pulping. Pulpwood quality classes based upon these or other stem characteristics can readily be established from stem quality inventory data. The ability to stratify pulpwood into such quality classes is important in appraising suitability for specific pulping processes and handling methods.

Application To Additional Products

The preceding examples of how to appraise stand product potential by using inventory data are by no means exhaustive. Changes in utilization patterns and consumer demands may focus attention on other, perhaps newly developed products. As additional products become of interest, the appropriate stand volumes and quality criteria can be selected from existing inventory data to estimate stand potential.

Raw material quality standards also change with time. New quality standards are developed to meet the needs of new products, and existing standards are revised. Most such standards will incorporate as primary grading

unduly restrict the utilization potential for specific products, and the frequency with which they occur in the stand. He needs to know how much the utilization potential for specific products is affected by stem size distribution. With this type of stand information, timber managers have a basis for making management decisions. They can adequately assess the effect of a given stand treatment upon present and future product potential.

Detailed inventory knowledge of the timber resource and its potential is also indispensable to the wood industry, and to those concerned with guiding industrial development. Optimum utilization of timber has long been hampered by inadequate characterization of the raw material. Inventory information forms a reliable basis for interproduct comparisons in determining optimum use of the resource.

An analysis of multiproduct potential on the study area was presented in a preceding section. The information developed can be aggregated and summarized in the manner shown in table 7. Two examples will perhaps show how to apply such information.

In the locale represented by the study area, widespread interest has been shown in the development of a plywood industry. Existing criteria some of the stem quality features described by inventory data. Stand potential for the particular product can be appraised or reappraised in terms of these new quality standards by selecting and applying appropriate stem quality information. The inventory system thereby provides a high degree of flexibility for future product quality appraisal needs.

MULTIPRODUCT INVENTORY INFORMATION AS A BASIS FOR DECISION

A multiproduct inventory system provides a wealth of information for both stand management and utilization planning. A primary objective of timber management is to produce salable raw material, within the restrictions imposed by other forest uses. A primary objective of timber utilization is to make the best use of the resource, within existing technology and produce demands. Both objectives require knowledge of the physical characteristics of the stand, and the effect of these characteristics upon product yield and quality. A multiproduct inventory system can provide such information.

The timber manager needs to know which products the stand can and should be directed toward. He needs to know which stem features

Table 7.--Net product potential per acre, by diameter class, on the study area

D.b.h. class (Inches)	Net saw log volume by log grade		Net veneer log volume by bolt quality class			Net pole potential by height class			Net pulpwood volume
	3 & Better	4 - 5	1	2	3	20-30 ft.	30-40 ft.	40 ft. & over	
	Bd. ft. per acre		Bd. ft. per acre			Number per acre			Cu. ft. per acre
8	--	--	--	--	--	--	--	--	94
10	--	--	--	--	--	0	0	0	87
12	4	196	0	0	202	0	0	0	66
14	9	164	3	0	168	0	0	0	51
16	26	163	0	19	138	0	0	0	50
18	24	322	14	18	318	0	0	0	86
20	84	335	15	60	300	--	--	--	85
22	103	469	15	71	420	--	--	--	103
24	64	468	10	29	443	--	--	--	90
26	57	277	16	41	261	--	--	--	56
28	46	337	0	39	282	--	--	--	53
30	27	98	0	22	106	--	--	--	19
32	19	40	0	10	49	--	--	--	9
34	17	8	0	8	17	--	--	--	2
36	17	9	9	0	17	--	--	--	4
38	19	9	0	5	23	--	--	--	1
Total per acre	516	2,895	82	322	2,744	0	0	0	856

Figure 17.--Poor pruning characteristics can severely limit commercial pole potential.

timber quality information is not entirely adequate, however, for an appraisal of veneer potential. The net quantity and quality of potential veneer log material in the stand is shown in table 7. In addition, inventory information shows that the greatest quality (and quantity) potential exists in timber 18 through 26 inches in diameter. The effect of removal of given diameter class trees upon overall quality distribution can also be ascertained. Such an appraisal of potential provides industry with an adequate basis for making decisions and for production planning.

By referring to stem quality data for features affecting veneer potential (see table 4), it is apparent that excessive lean significantly reduces net potential. Management and cutting practices designed to reduce the incidence of lean may, in the long run, increase net veneer potential as much as 10 percent.

Commercial poles enjoy a relatively high value, compared to alternative primary products; consequently, pole potential is worth careful consideration. On the basis of diameter and height class distribution alone, a commercial pole potential could be assumed to exist in the stand. The stem quality information provided by the inventory system shows that this initial assumption is quite misleading, however. No pole potential exists in any pole height class in the study area. For current utilization planning, this alternative is removed from further consideration.

Reference to table 5 indicates that knots or limbs, crook, and lean (compression wood) are the primary stem features limiting pole potential. Knots or limbs exceeding allowable limits are by far the most important limiting factor (fig. 17). Stand management practices designed to accelerate natural pruning and height growth, or artificial pruning of potential pole stems, may in time develop a net pole potential in the stand. If such practices are not considered feasible, stand management should be directed toward other products. Future potential for poles will probably remain quite low.

These brief examples illustrate how multiproduct inventory information applied on a broader scale, such as for a compartmentized working circle, can be used to reach meaningful utilization and stand management decisions.

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** Address requests for copies to the originating office.*

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1965. A method of evaluating multiproduct potential in standing timber. U. S. Forest Serv. Res. Paper RM-15, 24 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Method described will: (1) remove observer bias from stand quality inventory; (2) provide a record of frequency of occurrence of stem features that affect product quality and yield; (3) characterize and quantify suitability of the timber resource for a broad range of products; (4) provide adequate multiproduct quality and yield information for management and utilization decisions; and (5) provide a continuing basis for such decisions through time.

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U. S. Forest Service
Research Paper RM-16
November 1965

The Weather and Climate of a High Mountain Pass in the Colorado Rockies

by

Arthur Judson

Rocky Mountain Forest and Range Experiment Station
Forest Service U. S. Department of Agriculture

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THE WEATHER AND CLIMATE OF A HIGH MOUNTAIN PASS

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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Judson, Arthur

The weather and climate of a high mountain pass in the Colorado Rockies. U. S. Forest Serv. Res. Paper RM-16, 28 pp., illus.

ERRATA

Page 8 - Tabulation, column 1. Dates for 48 hrs. and 72 hrs. snow fall amounts should be transposed.

Page 9 - Line 2, second paragraph, should read, "Average maximum depth ...

Page 16 - Table 5. Headings under "Corresponding surface wind at Berthoud Pass" should read:

	Within ±22.5°	Greater than ±22.5°

Page 20 - Last paragraph, line 3. Delete the word, four.

Page 28 - Figure 26. Regression equation should read: $\hat{Y} = 0.79 + 0.94X$.

[1]Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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THE WEATHER AND CLIMATE OF A HIGH MOUNTAIN PASS IN THE COLORADO ROCKIES

by

Arthur Judson, Associate Meteorologist

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The Weather and Climate of a High Mountain Pass in the Colorado Rockies

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The need for avalanche control to protect lives and property is becoming more apparent in the Colorado Rockies where winter sports are skyrocketing and automobile travel is constantly increasing. Basic to avalanche research, however, are weather and climatic data representative of Colorado's avalanche zones at elevations between 10,000 and 12,000 feet mean sea level (m.s.l.).

The snow and weather data accumulated at Berthoud Pass (figs. 1,2) during the past 15 years, plus information collected irregularly for several preceding years, constitute one of the most complete sets of winter-environment records ever taken in the western alpine region. The data gathered by several individuals and agencies have been assembled and published here because of their importance to mountain meteorology and avalanche-control planning. Data are presented by two periods: I--Winter (November 1 - April 30), and II--Spring-Fall (May 1 - October 31); basic data are in the appendix (tables 7-15 and figures 23-26).

Berthoud Pass is in north-central Colorado, 45 miles west of Denver. The first all-weather mountain highway to traverse the Colorado Rockies, U.S. 40, crosses the Continental Divide at Berthoud Pass. The presence of numerous avalanches along and adjacent to the highway (Frutiger 1964)[2] and the winter resorts in this heavily traveled area, together with the accessibility of power, make the Berthoud Pass vicinity a desirable location for alpine snow and avalanche research.

The Pass is on an east-west section of the Continental Divide (latitude 39°48'N., longitude 105°47'W), at an elevation of 11,315 feet m.s.l. Peaks rise 1,000 to 2,000 feet above the Pass on both the east and west (fig. 2). Mature Engelmann spruce and subalpine fir are the dominant vegetation, with the upper limit of tree growth at 11,800 feet.

BACKGROUND INFORMATION

Mr. Clyde E. Learned,[3] Senior Highway Engineer, U. S. Bureau of Public Roads, began recording snowfall and snow depth at Berthoud Pass in 1926, and continued until 1939; however, several periods of record between 1926 and 1931 were not located. No data were taken from 1940-41. From 1942 to 1949, the U. S. Forest Service recorded snow depths. On October 1, 1949, W. M. Borland,[3] Hydrologist, U. S. Bureau of Reclamation, established the weather station at the Pass in cooperation with the 5002nd USAR Research and Development Unit (Tng.), Elmer E. Fryar Army Reserve Center, Federal Center, Denver, Colorado.

The U.S. Forest Service took over the station in 1950 as part of its avalanche-forecasting program, and in January 1951 assigned Richard M. Stillman[3] as the avalanche hazard forecaster. Fairly complete records are available for the 1950-61 winter period, November 1 through April 30. Year-round daily observations were initiated in June 1961. In September 1963, Berthoud Pass became an official U.S. Weather Bureau Climatological Station.

During the 1926-39 period, the master snow-depth stake was in a clearing a quarter of a mile north of the Pass; new-snow depths

[2] *Names and dates in parentheses refer to Literature Cited, p. 23.*

[3] *The author wishes to thank Messrs. Borland, Learned, and Stillman for the generous use of the original data which made this publication possible.*

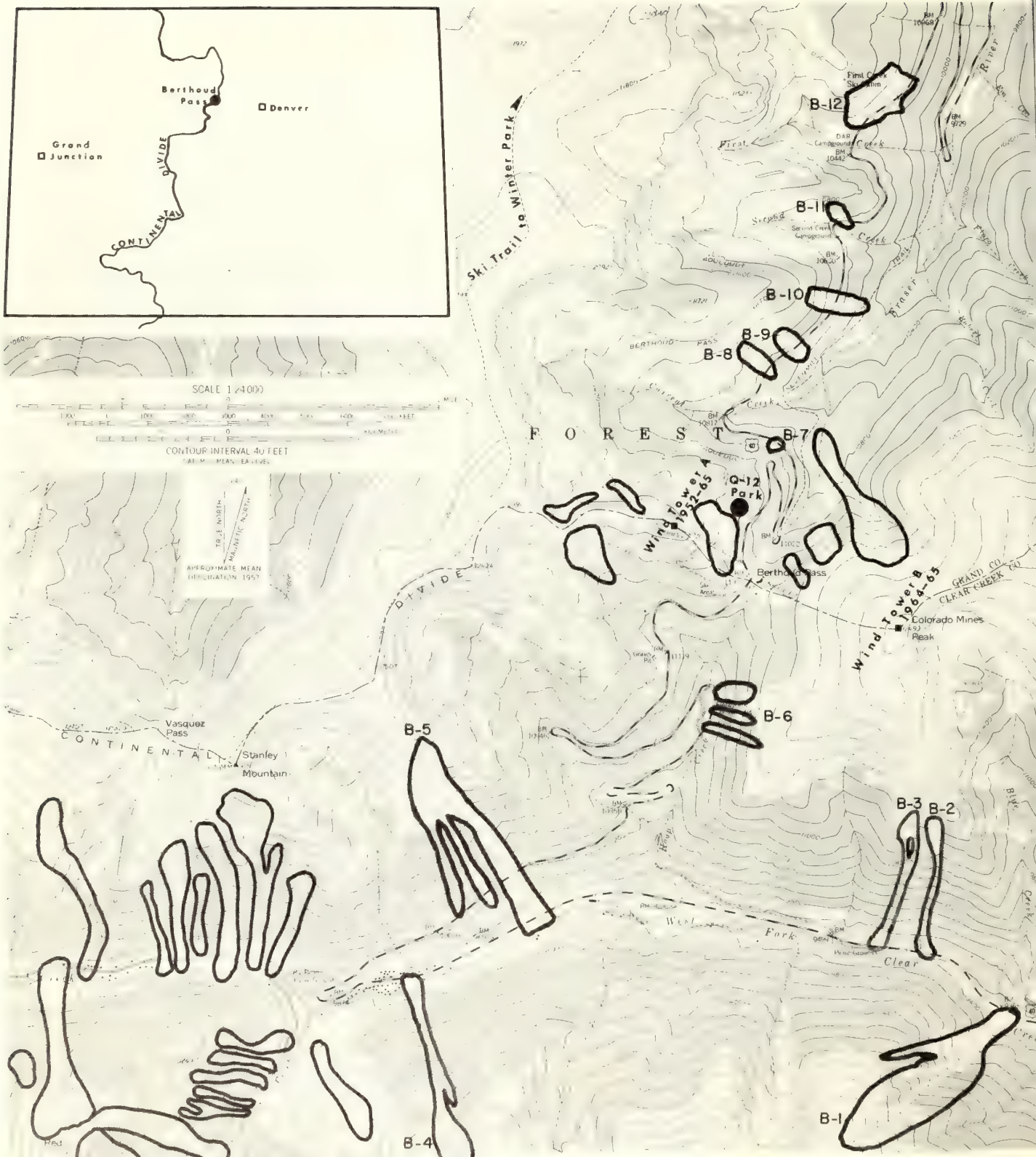


Figure 1.--Avalanches that threaten travelers on U. S. Highway 40 in Berthoud Pass area, numbered B-1 through B-12, are described by Frutiger (1964). Unnumbered avalanche areas menace mining operations, Denver Water Board access roads, and Berthoud Pass ski area.

Figure 2.--U. S. Highway 40 crosses Continental Divide at Berthoud Pass, 45 miles west of Denver, Colorado. The peaks on the east and west rise 1,000 to 2,000 feet above the Pass.

Colorado Mines Peak as seen from the upper terminal of chair lift above Berthoud Pass, January 4, 1964. Wind tower B was installed on the exposed summit at 12,493 feet m.s.l. in 1964.

Summit of Berthoud Pass as seen from Colorado Mines Peak, April 23, 1963. A, ski lodge and snow ranger's station; B, upper terminal of chair lift on ski area.

were measured at the present ski lodge site. When measuring was resumed in 1942, the master stake was 50 feet east of the lodge. In 1949, a precipitation tower was constructed and all instruments, including the snow depth stake, were relocated 100 feet northwest of the lodge. Maximum and minimum liquid-in-glass thermometers and a hygrothermograph were installed in a standard cotton region shelter. Mounted on top of the tower were a standard 8-inch rain and snow gage with its orifice 16 feet aboveground, a 3-cup anemometer with the cups 19 feet aboveground, and the instrument shelter with its base 11 feet 4 inches above the ground (Borland 1952).

In December 1951, a Leopold Stevens Q-12 recording precipitation gage[4] was installed in a clearing a quarter of a mile northwest of Berthoud Pass--since called Q-12 Park (fig. 3). In November 1959, however, the Q-12 gage was replaced with a Bendix Friez 775-B recording rain and snow gage, the orifice of which was placed 13 feet 4 inches aboveground. The master snow-depth stake and 8-inch gage were moved to Q-12 Park in December 1952. New-snow depths have been measured at the Q-12 location on a white snowboard since that date.

The instrument shelter, moved to Q-12 Park on August 29, 1963, was mounted inside a metal frame (fig. 3) so the bottom of the shelter can be kept approximately 4 feet above the snow surface throughout the winter.

A new precipitation tower was constructed in Q-12 Park in October 1964. The orifices of the recording gages on this tower are 14 feet 10 inches aboveground. Also installed at Q-12 Park that year was an experimental 12-foot-diameter pressure pillow (fig. 3) which, with a type F water-level recorder, will record the water equivalent of the snowpack on the ground. The pillow, developed by the U.S. Soil Conservation Service, has been successfully used in other western States.[5]

[4] *Trade names and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

[5] *Personal communication with Robert Beaumont, U. S. Soil Conservation Service, Portland, Oregon, 1964.*

Bimonthly stratigraphic section data have been taken regularly at Q-12 Park for the past 15 winters. Pits were dug to expose the layers of snow on the ground. Data for each layer include: (1) temperature, (2) density, (3) settlement, (4) hardness, (5) resistance to penetration, (6) crystal type, and (7) grain size. These data will be analyzed and published later.

The anemometer, located northwest of the ski lodge in 1949, was moved on January 27, 1952, to a point 325 feet west of the upper chair-lift terminal at an elevation of 11,900 m.s.l., where it was mounted 12 feet aboveground on a steel tower. An Esterline Angus operations recorder, installed at the snow ranger's headquarters, continuously records windspeed and direction. In November 1961, the anemometer tower was moved to 10 feet north of the upper chair-lift terminal, and was mounted on the northwest corner of the lift operator's shack. The beaded, conical 3-cup anemometer was then 24 feet aboveground. The anemometer was moved again on August 29, 1963, to a site 100 feet west of the lift operator's shack, at 11,880 feet m.s.l., where it was mounted on a 33-foot tower (wind tower A, fig. 1; fig. 4).

In October 1964, a new wind station (wind tower B, fig. 1) was established on the exposed summit of Colorado Mines Peak at 12,493 feet m.s.l. Mounted on the tower, 39 feet aboveground, are windspeed and direction sensors, which are continuously recorded at the snow ranger's station at Berthoud Pass.

A partial list of the instruments operated during the avalanche season (November 1 through April 30), and the number of winters when data were recorded are:

	Number of winters
Barograph	13
Microbarograph	2
Standard mercurial barometer	3
Esterline Angus operations recorder (windspeed and direction)	14
Heated tipping bucket rain gage	3
Generating anemometers	3
Hygrothermographs	15
Temperature probes:	
In the snowpack	15
In the soil	2
On the anemometer tower	2

Pressure pillow to record water equivalent of snowpack on the ground. October 2, 1964.

Figure 3.--Q-12 Park, located one-fourth mile northwest of Berthoud Pass, has an average radius of 60 feet, an east exposure, and an average slope of 6 percent. The 60- by 120-foot area, well protected from wind, was artificially leveled in the fall of 1955. Mature Engelmann spruce and subalpine fir, 20 to 60 feet high, surround the opening.

Precipitation recording gage, shelter, and snow stakes. January 4, 1964.

Looking east over Q-12 Park to Mount Parry and Mount Eva on the Continental Divide, January 14, 1964.

Instrument shelter and snow-depth stake. Colorado Mines Peak in background. May 13, 1964.

NW
Jan. 4

NNE
Jan. 4

SW
May 13

W
Jan. 3

Figure 4.--Four views from Berthoud Pass anemometer, 1964.

PERIOD I: WINTER (NOVEMBER 1 - APRIL 30)

Thermal Regime

The small temperature variations typical of ridge-crest stations are common at Berthoud Pass (fig. 5; table 1), where the average daily range is only 15° F. in January. Maximums rarely exceed 32° F., and below-zero minimums are frequent during December, January, and February. Minimums below -25° F. are rare because terrain features and exposure are not favorable for the development of temperature inversions. The lowest temperature on record is -35° F. on February 1, 1951; the highest winter maximum, 56° F. on April 26, 1963.

Table 1.--Thermal regime at Berthoud Pass, Colorado, during winter period, November 1 - April 30, 1949-64

Period I	Mean	Maximum temperature			Minimum temperature			Average days--	
		Mean	Median	Extreme	Mean	Median	Extreme	Below 0° F.	Above 32° F.
	Degrees F.							Number	
November	20	29	31	47	11	12	-25	5	13
December	12	20	20	41	5	6	-23	9	3
January	11	18	19	40	3	4	-28	10	2
February	12	20	20	42	4	4	-35	9	3
March	16	25	26	49	6	6	-20	7	6
April	25	35	35	56	15	15	- 4	0.5	17

Snowfall

The snowfall season normally begins in September and ends in June. Mean annual snowfall for 1950-64 was 361 inches, with 289 inches falling from November through April:

	1931-39		1949-64
	Sept.-June (Inches)	Nov.-Apr. (Inches)	Nov.-Apr. (Inches)
Seasonal snowfall:			
Mean	413	347	289
Maximum	507	414	414
Minimum	318	278	169
Median	418	354	266

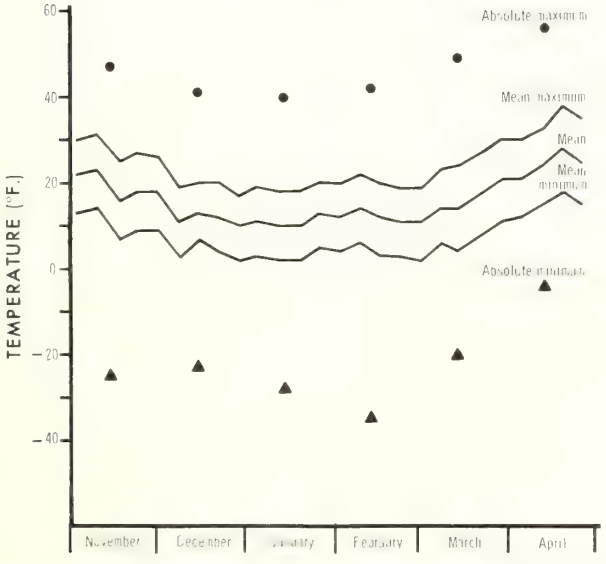
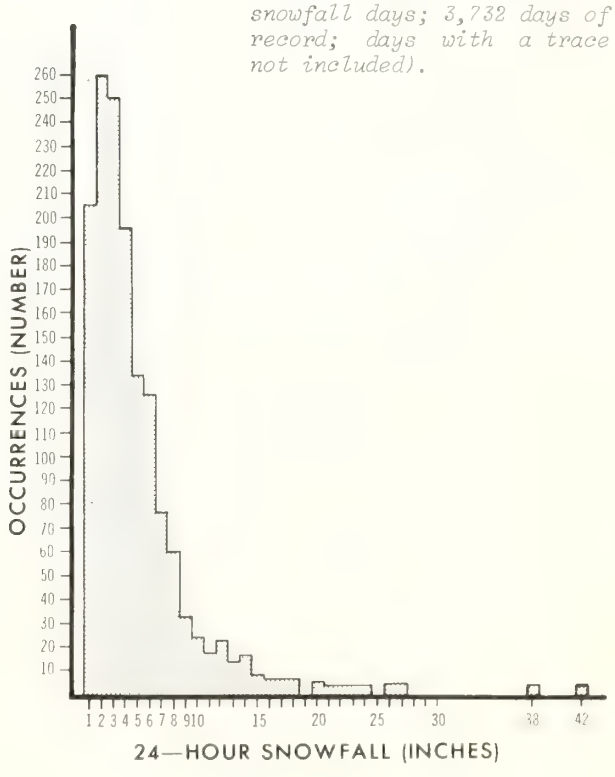


Figure 5.--Winter march of temperature (°F.)--7-day means and extremes. November through April 1949-64.

Snowfalls are frequent and light. They occur on 50 percent of the days (including traces), and exceed 12 inches only 3 percent of the time, although 24-hour snowfalls up to 42 inches have been recorded (fig. 6). The maxi-

Figure 6.--Distribution of 24-hour snowfalls at Berthoud Pass, November 1 - April 30, 1931-39 and 1949-64 (1,420 snowfall days; 3,732 days of record; days with a trace not included).



mum seasonal snowfall was 507 inches in the winter of 1932-33 (Learned 1939). The greatest snowfall in a calendar year was 518 inches in 1957.

Berthoud Pass receives about 20 percent more snowfall than other stations in the Front and Tenmile ranges (Borland 1963). Other stations are located at Loveland Basin, Arapaho Basin, Breckenridge (Peak 8), and the high-altitude observatory at Climax. The difference is related to the greater orographic effect at Berthoud Pass.

Snowfall intensities average 0.5 inch per hour during most storms, and sustained intensities exceeding 1 inch per hour are unusual even during major storms. Very high snowfall rates do occur about once every 4 years, however. The highest snowfall rates recorded at Berthoud Pass are:

	New snow		
	Rate (In./hr.)	Amount (In.)	Date
Time period:			
1 hr.	7.00	7	Feb. 25, 1934
2 hrs.	6.50	13	Feb. 25, 1934
13 hrs.	2.77	36	Apr. 21, 1933
24 hrs.	1.75	42	Apr. 21, 1933
48 hrs.	1.67	80	Apr. 20-22, 1933
72 hrs.	1.31	94	Apr. 20-21, 1933

Snowfalls of this magnitude have also been recorded at nearby Silver Lake, 19 miles north-northeast of Berthoud Pass, where 76 inches of snow fell in a 24-hour period on April 26, 1922--the largest 24-hour snowfall recorded to date in the United States (Ludlum 1962).

New Snow

Densities of 24-hour snowfalls during the winter months (fig. 7) show a mean value of 0.07 gram per cubic centimeter (g/cm^3), or a snow-water depth ratio of 14 to 1. The median and mode are also 0.07 g/cm^3. Only 8 percent of the total snowfalls had density values greater than 0.10 g/cm^3. Densities were computed from the ratio of the water equivalent to the new snow depth, measured by core samples taken from a white snowboard.

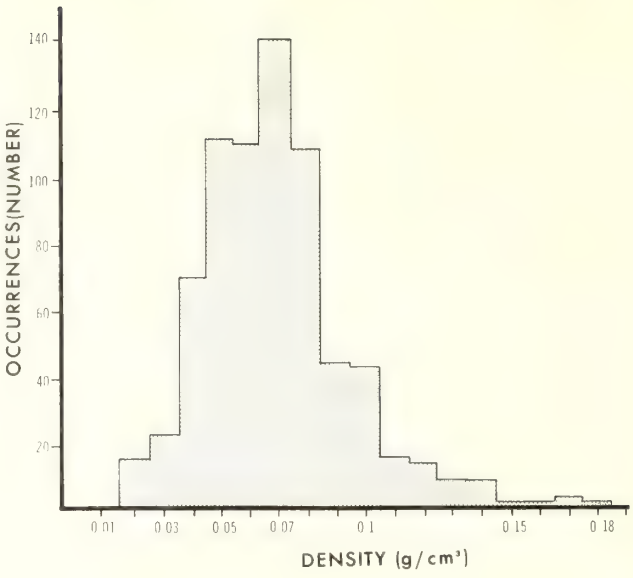


Figure 7.--Distribution of 24-hour snowfall density, Berthoud Pass, Colorado, 1949-64.

New-snow crystal types, classified according to the International Classification for Snow (Canada Natl. Res. Council 1954) and recorded for most snowfall days 1957-63, were distributed as follows:

Classification symbol:	Crystal form	Percent occurrence
F-7	Irregular	29
F-2	Stellar	24
F-5	Spatial dendrites	21
F-1	Plates	12
F-8	Graupel	9
F-4	Needles	2
F-9	Ice pellets	2
F-6	Capped columns	1
F-3	Columns	0
F-10	Hail	0

Surface hoar commonly forms during periods of clear, cold weather, but depths exceeding 1 inch are unusual. In the Berthoud Pass vicinity, rime ice accumulations below 12,000 feet m.s.l. are insignificant. Only once during the 15 winters of record has sufficient rime developed to inhibit the functioning of exposed instruments (fig. 8).

Figure 8.--Some rime ice has been encountered at wind tower B on the exposed summit of Colorado Mines Peak.

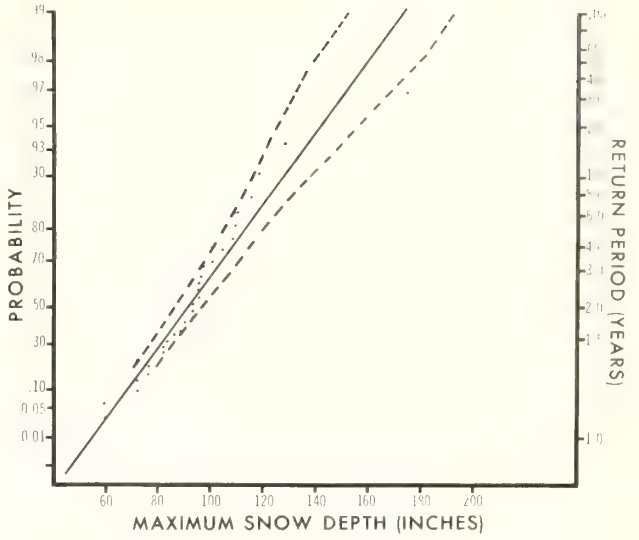


Figure 10.--Return periods for maximum snow depths; 30 years of record. (Shows least squares line of best fit and one standard error envelope.)

Snowpack

The seasonal snowpack begins in late October and reaches its maximum depth in mid-April (fig. 9). A continuous snow cover usually remains until the third week in June, although it may last until early July in years when May snowfalls are heavy and June temperatures are below average.

Recorded peak snow depths range from 60 to 174 inches. Average depth for the 1942-64 period was 88 inches. Return periods for maximum snow depths for 30 years of record (fig. 10) were determined by Gumbel's (1958) procedure.

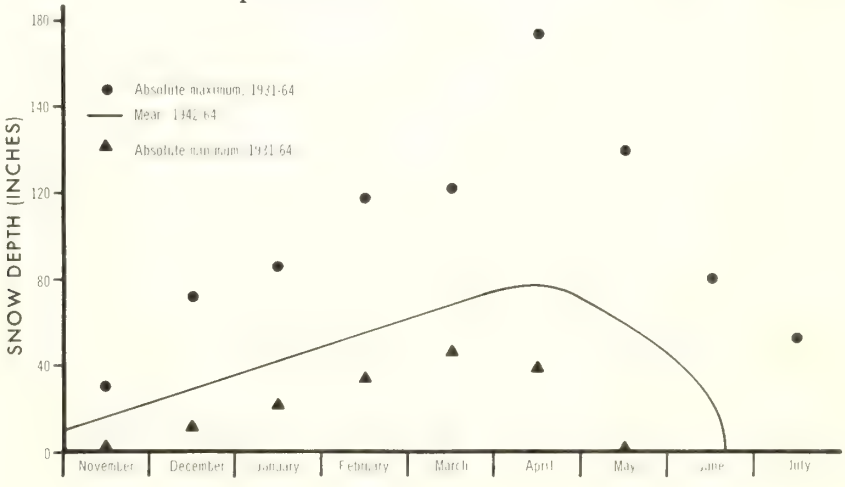


Figure 9.--Snow depths at Berthoud Pass (see appendix, tables 11 and 12).

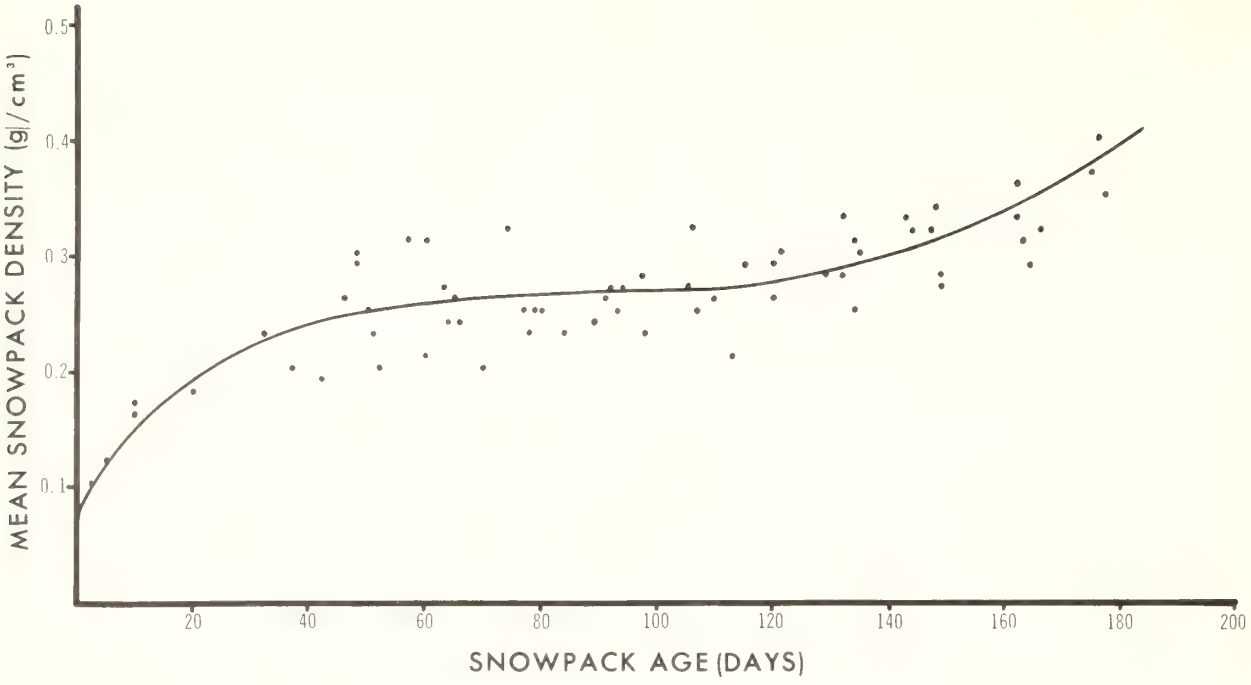


Figure 11.--Snowpack densification at Berthoud Pass, 1953-60.

Destructive metamorphism proceeds very slowly in the pack at Berthoud Pass. The combination of low temperature, porous snow, and shallow snow depth delays densification and causes the formation of large quantities of depth hoar near the ground. The low strength properties of these large, unstable crystals is a primary cause of avalanching in the alpine regions of this continental climate.

A rapid rise in density (fig. 11) during the first 20 days is followed by a marked decrease in rate of densification. More than 140 days are required before the mean snowpack density[6] reaches a value of 0.30 g/cm³. After 140 days, the rate of densification gradually increases due to accelerated destructive metamorphism accompanying higher temperatures. The persistence of a low-density snowpack throughout the winter is largely responsible for the abundance of "rotten snow" found in the Rockies in May and June--whenever air temperatures are above freezing, over-snow travel is difficult and tiring. The layer of coarse-grained crystals and associated depth hoar becomes progressively more fragile as the pack becomes isothermal. This phenomenon, discussed by La Chapelle (The Mountaineers, Seattle 1960, chapter 21), is particularly evident on timbered north slopes.

[6] *For engineering purposes, the weight of the snowpack in pounds per square foot may be calculated by multiplying the water equivalent in inches by 5.2; density of 0.5 g/cm³ is assumed.*

Wind

Windspeed and direction have been recorded at Berthoud Pass since January 1952. Six-hour averages of speed and direction, starting at 0000 hours each day, are available for the period of record (figs. 12, 13), with original strip charts available since November 1962.

The anemometer is located near the upper terminal of the chair lift on a ridgetop half a mile west of the Pass at 11,880 feet m.s.l. (see fig. 4). In addition, windspeed was con-

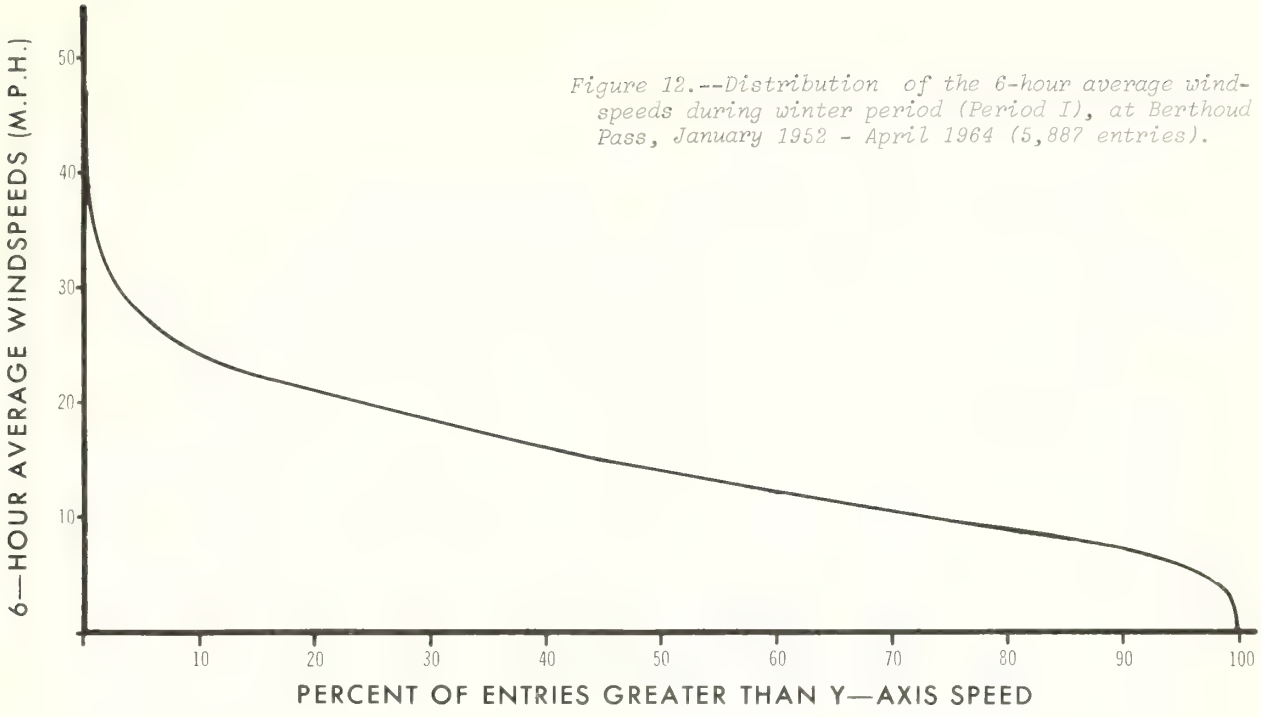


Figure 12.--Distribution of the 6-hour average windspeeds during winter period (Period I), at Berthoud Pass, January 1952 - April 1964 (5,887 entries).

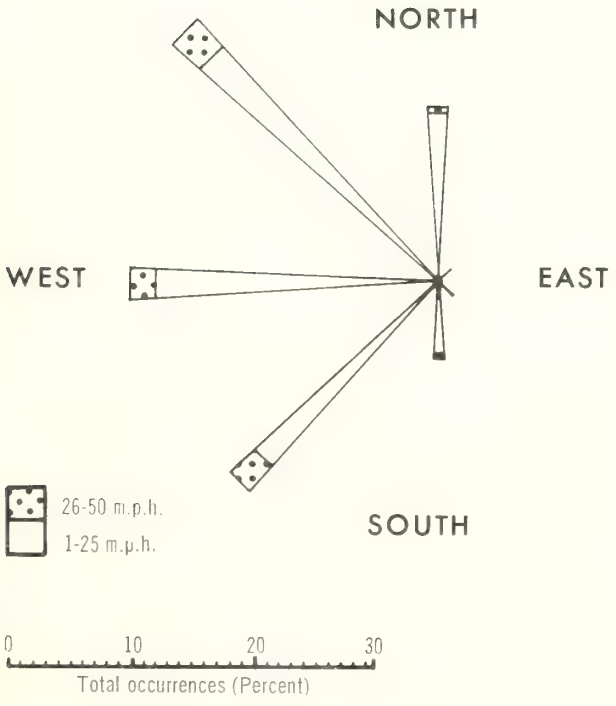


Figure 13.--Distribution of 6-hour average windspeeds and directions during winter period (Period I), at Berthoud Pass, January 1952 - April 1964.

tinuously recorded from a generating anemometer, Weather Bureau specification F 420-C, during the winter of 1963-64.

Wind Direction

The prevailing wind direction, based on 8 compass points and 6-hour averages, is from the northwest (fig. 13). Data for 2 winters based on 16 points indicate a prevailing direction of west-northwest. Winds from the northwest, west, and southwest account for 76 percent of all wind directions; 20 percent are from the north and south; and only 4 percent are from the northeast, east, and southeast. During the early winter months, northwesterly winds prevail; in March and April (fig. 14), west and southwest winds prevail, and are associated with higher temperatures and increased precipitation.

Windspeeds at Berthoud Pass

The average winter windspeed is 16 miles per hour (m.p.h.). Changes in hourly windspeeds are gradual and follow a trend of either rise or fall over a period of 4 hours or more (see fig. 12). The highest 5-minute speed for

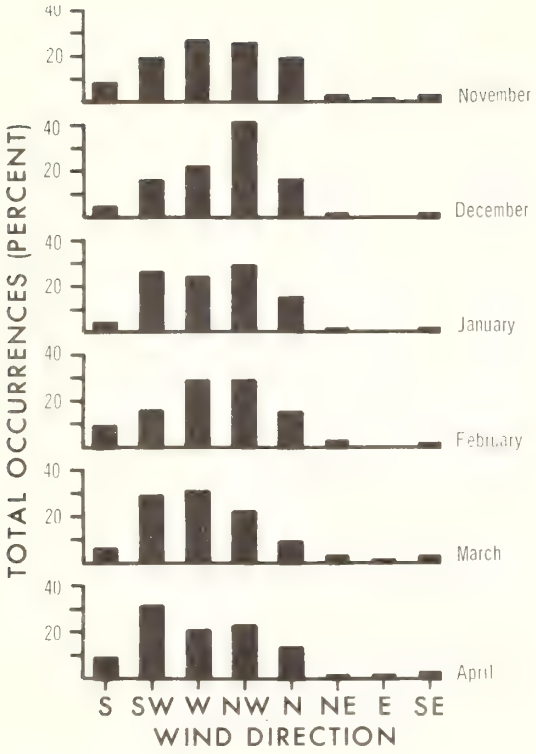


Figure 14.--Wind direction, in percent of occurrences, November - April 1951-64.

a given hour is seldom more than 10 m.p.h. greater than the hourly average. Sharp increases in speed do occur, however, and coincide with the advent of gusty periods. Recorded windspeeds have increased from 20 m.p.h. to 55 m.p.h. in less than 3 seconds.

At the chair-lift site, 6-hour average windspeeds exceed 30 m.p.h. only 3 percent of the time; they occasionally exceed 40 m.p.h. Marr (1961) noted spectacular increases in windspeed with increasing exposure; this has been experienced also at Berthoud Pass. Records from wind tower B, established October 1964 on Colorado Mines Peak east of Berthoud Pass (see fig. 2), show 6-hour averages that frequently exceed those at the chair-lift site by a factor of two or more through all speed ranges. During December 1964, 1-hour averages up to 83 m.p.h. and peak gusts to 108 m.p.h., corrected, (U. S. Weather Bureau et al. 1963) were recorded at wind tower B. Some rime ice has been encountered at this site (see fig. 8).

The maximum speeds for the period of record at the chair-lift site are not known since the recorder was out of order during some of the windiest periods. In one such instance, a 200-pound transformer was blown from a platform near the anemometer.[7] A 1-minute speed of 95 m.p.h. was recorded on December 24, 1955. The highest recorded windspeeds at the chair-lift site, January 1952-April 1964 are:

	Highest speed recorded (m.p.h.)	Date	Direction
Time interval:			
1 minute	95	Dec. 24, 1955	SW
1 hour	55	Jan. 31, 1963	SW
6 hours	49	Jan. 31, 1963	SW
12 hours	45	Dec. 24, 1955	SW

[7]*Personal communication with Richard M. Stillman, U. S. Forest Service, Denver, Colorado, 1961.*

Table 2.--Ratio of peak gusts to the 5-minute average windspeeds, November 12, 1963 - January 20, 1964

Item		November	December	January	Period
Number of 5-minute samples	N	194	1,204	1,047	2,445
Mean ratio of peak gusts to the average 5-minute windspeeds	R	1.40	1.51	1.57	1.53
Maximum ratio of peak gust to the 5-minute windspeed	R max.	1.82	2.40	2.61	2.61
Average windspeed in m.p.h.	μ	11.5	14.7	15.9	14.0

24 hours	40	Dec. 24, 1955	SW	40-49	2.00
1 month	19	Jan. 1953	--	50-59	1.68

Gustiness.--Data on maximum windspeeds of the type used for structural-design criteria are rare for the mountainous areas of the western United States. Gust factors at the Berthoud Pass chair-lift site were computed for November 12, 1963 to January 20, 1964, from data recorded with the generating anemometer. A 100-percent sample was taken, in which the criteria were 5-minute averages greater than or equal to 20 m.p.h. that contained at least one gust with a range of 10 m.p.h. or greater. There were 2,445 5-minute periods, or 13 percent of the total, that qualified. The mean ratio of the peak gusts to the 5-minute average windspeeds was 1.527 (table 2). Winner (1963) found a similar value using data from the Rhein-Main airport in Germany.

During the sample period at Berthoud Pass, the maximum gust was 88 m.p.h. Maximum gust ratio by speed classes was:

Average 5-minute speed in m.p.h.	Maximum gust ratio
20-29	2.61
30-39	2.46
40-49	2.00
50-59	1.68

Less than 1 percent of the samples fell in the two higher speed brackets, with only 4 percent exceeding 1.9. The mean ratio of the peak gusts to the 1-hour average speeds was 2.0 for the sample period. Windspeeds during November and December 1963 were slightly below average.

Windspeeds at Other Mountain Locations

Windspeeds vary greatly in the mountainous areas throughout the world (table 3), but the average monthly windspeeds at or near 12,000 feet m.s.l. in the north central Colorado Rockies are similar to those recorded at several alpine areas of western United States and Europe. The large mass of rough, mountainous terrain that extends several hundred miles west of Colorado's Front Range plays an important role in decreasing extremely high windspeeds that might otherwise be expected. As mentioned earlier, average windspeed at Berthoud Pass is 16 m.p.h.; on more exposed sections of the Front Range, the win-

Table 3.--Mean monthly windspeeds at various mountain weather stations, in order of decreasing windspeeds, November 1, 1962 - April 30, 1963

Station	State or country	Elevation of anemometer	Monthly windspeeds					
			Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
		Feet m.s.l.	Miles per hour					
Mount Fuji[1]	Japan	12,388	42	42	47	37	43	34
Mount Washington[1]	New Hampshire	6,262	25	36	39	49	41	36
Jungfraujoch[1]	Switzerland	11,729	27	29	25	24	26	25
Niwot Ridge[1]	Colorado	12,300	21	25	26	24	22	21
Pole Mountain[1]	Wyoming	8,200	22	22	21	21	18	--
Old Glory[1]	British Columbia	7,700	18	19	--	18	18	--
Pic du Midi[1]	France	9,381	15	19	20	17	20	17
Sonnblick[1]	Austria	10,191	22	16	18	15	18	15
Berthoud Pass[1]	Colorado	11,880	15	15	17	17	16	17
Arapaho Basin[1]	Colorado	12,400	--	--	--	15	14	15
Zugspitze[1]	Germany	9,718	13	20	15	14	17	11
Mauna Loa[1]	Hawaii	11,150	15	12	19	15	13	10
Sandberg	California	4,517	12	13	15	13	16	14
Kodaikanal	India	7,654	12	14	14	15	13	12
Sexton Summit	Oregon	3,836	14	15	11	15	13	11
Stampede Pass[2]	Washington	3,958	12	11	13	13	11	11
Weissfluhjoch[1]	Switzerland	8,835	13	13	12	8	11	9
Dubois 15 NE[1]	Wyoming	9,600	11	11	12	11	11	10
Bald Mountain[1]	Idaho	9,000	--	--	12	9	13	--
Peak Eight[1]	Colorado	11,600	--	12	11	12	9	--
Loveland Basin[1]	Colorado	11,800	8	10	12	10	10	--

[1] Anemometer is above timberline or is located on a treeless area.
[2] Data from U. S. Weather Bureau, Asheville, North Carolina; m.p.h. entries based on monthly mean of 1-minute windspeeds taken once each hour from 0400 to 1900 PST daily.

Table 4.--Mean monthly windspeeds for 3 years of record at several Front Range stations in Colorado

Station	Year	Elevation at anemometer	Monthly windspeeds			
			Jan.	Feb.	Mar.	Apr.
		Feet m.s.l.	-- Miles per hour --			
Berthoud Pass	1965	11,880	17.3	15.7	14.0	15.8
Colorado Mines Peak	1965	12,493	29.0	28.9	23.7	23.0
Berthoud Pass	1964	11,880	16.3	15.1	15.5	16.9
Straight Creek Pass[1]	1964	12,500	25.2	23.3	23.2	22.7
Berthoud Pass	1953	11,900	19.0	17.0	16.0	--
Loveland Pass[2]	1953	12,000	20.0	18.0	16.0	--
Niwot Ridge[3]	1953	12,300	30.0	25.0	22.0	20.0

[1] 11.5 miles southwest of Berthoud Pass; averages prorated on basis of bimonthly readings; data by U. S. Forest Service.
[2] 11 miles southwest of Berthoud Pass; data from Colorado State Highway Department.
[3] 20 miles north-northeast of Berthoud Pass; data from Marr (1961).

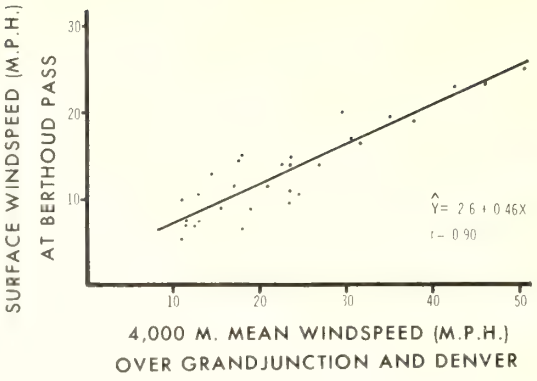


Figure 15.--Correlation of Berthoud Pass 12-hour average surface windspeeds with 4,000 m. windspeeds averaged for Denver and Grand Junction; SW, SSW, or S winds aloft; November - April 1962-63.

ter-month average is considerably higher--20 to 30 m.p.h. (table 4).

At Mount Washington, New Hampshire, (Blumenstock 1959) and the Jungfraujoch in Switzerland,[8] maximum hourly windspeeds exceeding 100 m.p.h. have been recorded; they have exceeded 90 m.p.h. at White Mountain, California (Pace 1963).

In the Colorado Rockies, the greatest recorded 1-hour average windspeed was on March 26, 1884 (U. S. Signal Office 1885), at 14,110 feet m.s.l. on the summit of Pikes Peak--112 m.p.h., corrected to 84 m.p.h. by means of the Robinson 4-cup hemispherical anemometer calibration curve (Brevoort and Joyner 1935).

Correlation with Winds Aloft

Because windspeed is a major factor in avalanche formation, surface windspeeds at Berthoud Pass were correlated with the 3,000 and 4,000 meter (m.) winds at Grand Junction and Denver from November 1962 through April 1963. A poor correlation (correlation coefficient r = 0.30) and a high degree of scatter were found when values for short intervals (5 minutes, or 1- and 6-hour surface averages) were used. A good correlation (r = 0.90), however, significant at the 1-percent level, was found with 12-hour averages when winds aloft were from the southwest at both Denver and Grand Junction (fig. 15). Upper winds from the west and northwest showed a great deal of scatter. A correlation coefficient (r = 0.76) for surface and upper winds, regardless of direction, over a 6-day time interval (fig. 16) was significant at the 1-percent level. The data for 4,000 m. winds aloft showed a slightly higher correlation with surface winds than did the 3,000 m. winds.

Significantly, upper wind directions corresponded very closely to the surface directions when winds aloft were from the southwest (fig. 17). Particularly interesting is the

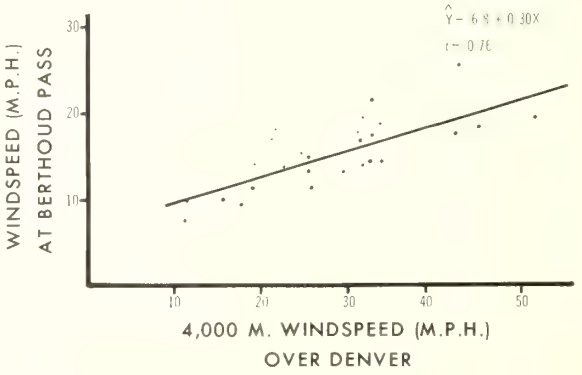


Figure 16.--Correlation of Berthoud Pass 6-day average surface windspeeds with 4,000 m. windspeeds over Denver, 16 directions, November - April 1962-63.

[8] *Personal communication with Dr. J. Haeflin, Chef des Wetterdienstes, Schweizerische Meteorologische Zentralanstalt, Zurich, Switzerland, October 14, 1964.*

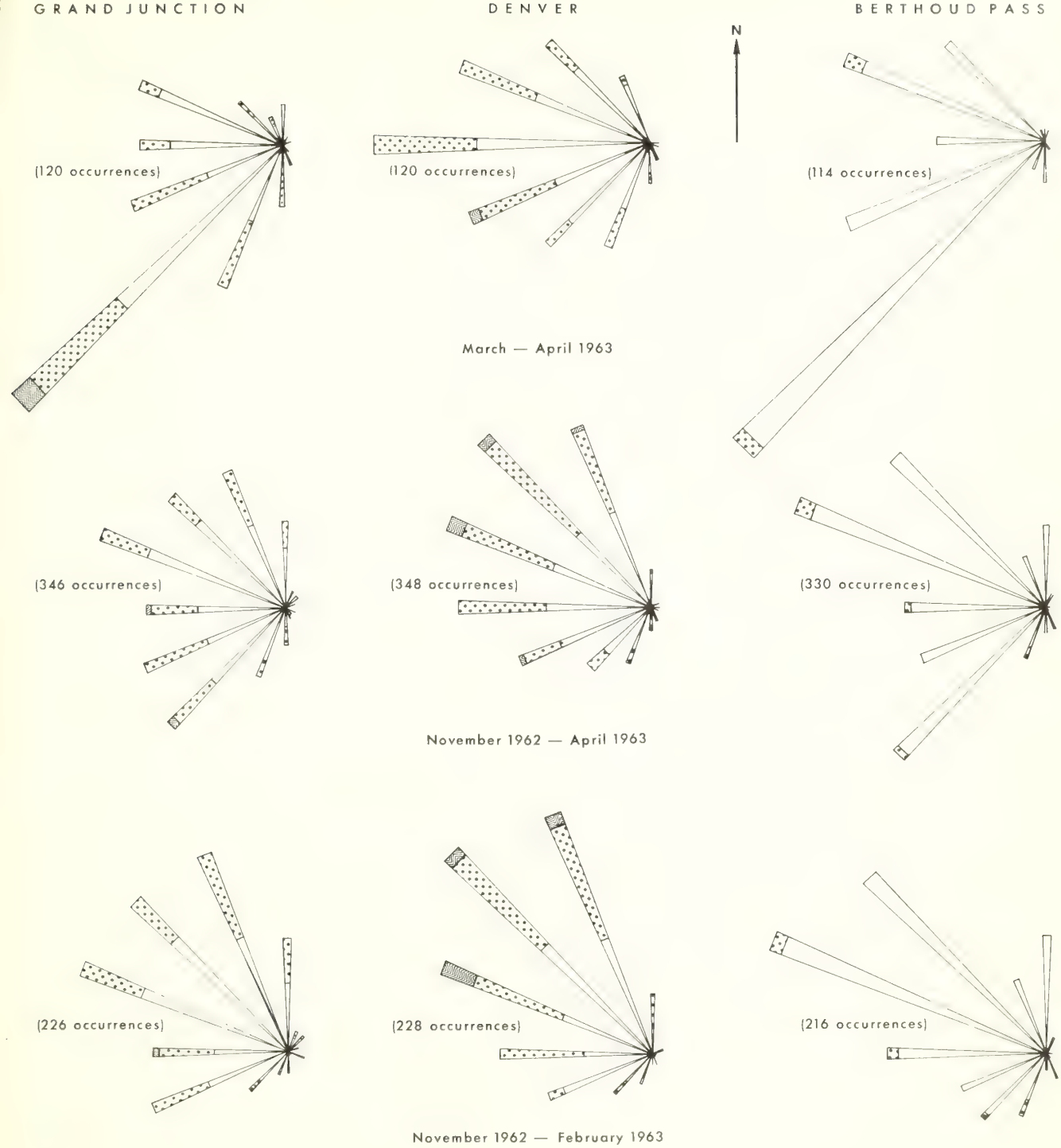


Figure 17.--Wind roses for three winter periods, 1962-63: Grand Junction and Denver, at 4,000 meters, 0000 and 1200 Greenwich mean time (G.m.t.); Berthoud Pass, at the surface, 2330-0030 and 1130-1230 G.m.t.

Table 5.--Comparison of upper wind directions (4,000 m.) at Grand Junction with surface winds[1] at Berthoud Pass, November 1 - April 30, 1963-64

Upper wind direction (4,000 m.) at Grand Junction	Total observations	Corresponding surface wind at Berthoud Pass	
		Within +22.5°	Greater than +22.5°
	Number	Number of occurrences	
N	15	2	13
N-NW	31	11	20
NW	31	22	9
W-NW	26	20	6
W	15	12	3
W-SW	23	18	5
SW	17	17	0
S-SW	7	7	0
S	4	1	3
All other directions	4	1	3

[1] No entries made when less than 15 m.p.h.

prevailing southwest wind during the March-April period at 4,000 m. for Grand Junction and at the surface at Berthoud Pass.

Winds from the west and northwest showed the next best correlation, while north winds showed little, if any, relation to surface wind directions. When wind directions at Berthoud Pass and Grand Junction were compared (table 5), southwest winds aloft at 4,000 m. over Grand Junction appeared as southwest winds at Berthoud Pass 76.5 percent of the time, and were within 22.5 degrees of that direction all of the time. At the other extreme, north winds over Grand Junction never indicated north winds at Berthoud Pass.

The proximity of higher ground to the west of the Berthoud Pass anemometer site appears to induce a variable local effect (depending on stability conditions) that introduces both speed and direction bias. To forecast winds over the more exposed sections of the Continental Divide from winds-aloft data, an anemometer on a more isolated peak might be more reliable. To test this hypothesis, wind sensors were installed in the fall of 1964 on the 12,493-foot summit of Colorado Mines Peak. Figure 18 shows a frequency distribution of Berthoud Pass winds and winds aloft at Denver and Grand Junction.

Major Storms

At Berthoud Pass, the onset of a major winter storm has always been extremely difficult to anticipate. The sparse network of reporting stations in the Rockies, together with complex terrain features, precludes the recognition of any well-defined fronts and associated storm centers. This section is intended to give only a general insight into the large-scale atmospheric circulations associated with intense winter storms at the Pass.

Storms were divided into four types and simplified maps prepared (figs. 19-22), based on the 300 millibar (mb.) jetstream orientation and the 500 mb. flow patterns:

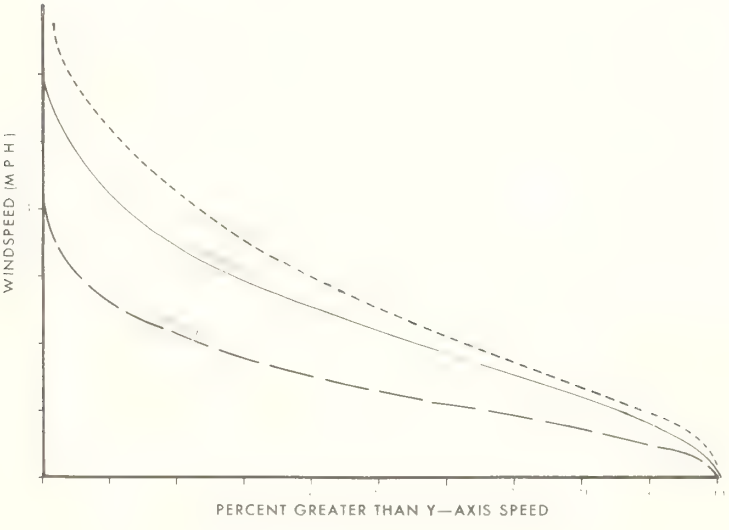


Figure 18.--Distribution of 5-minute average surface windspeeds at Berthoud Pass and 4,000 m. windspeeds over Denver and Grand Junction, November 5, 1962 - February 28, 1963.

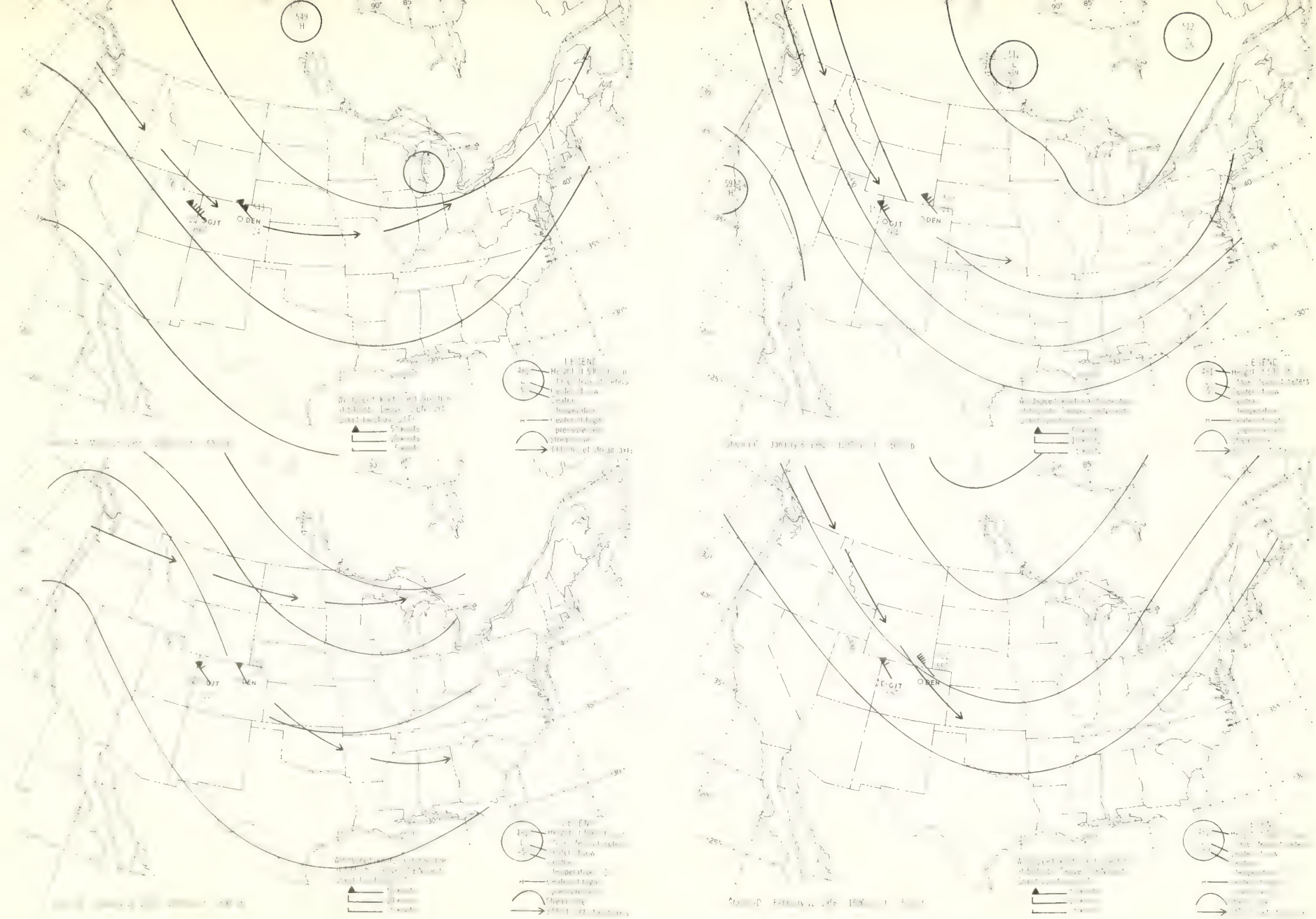


Figure 13.--Four stages of type I, 500 mb., Surface Fcst., Valid.

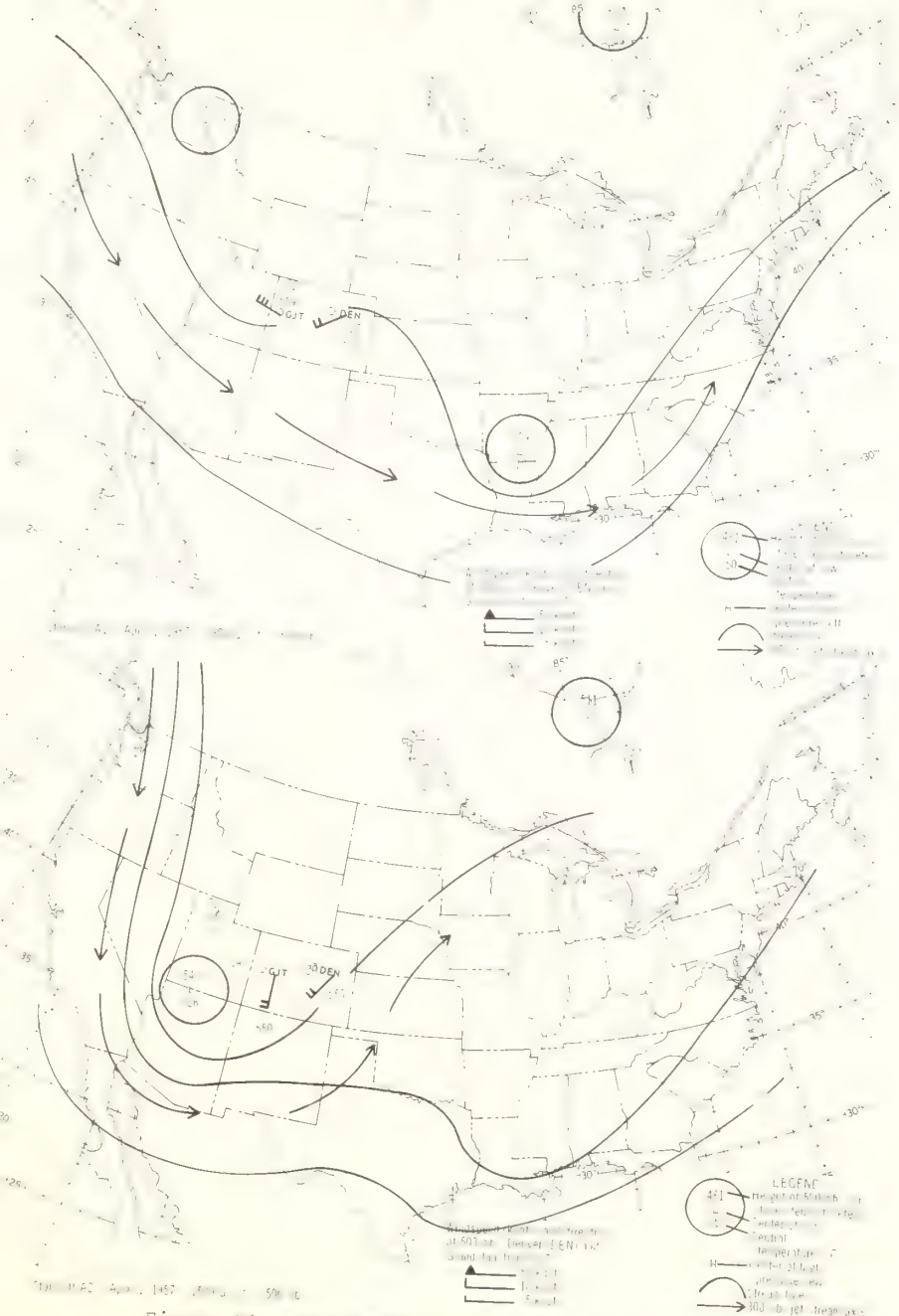


Figure 21.--Two storms of type III, each with four time sequences for storm IIIA and two for storm IIIB, Berthoud Pass, Colorado (continued on next page).

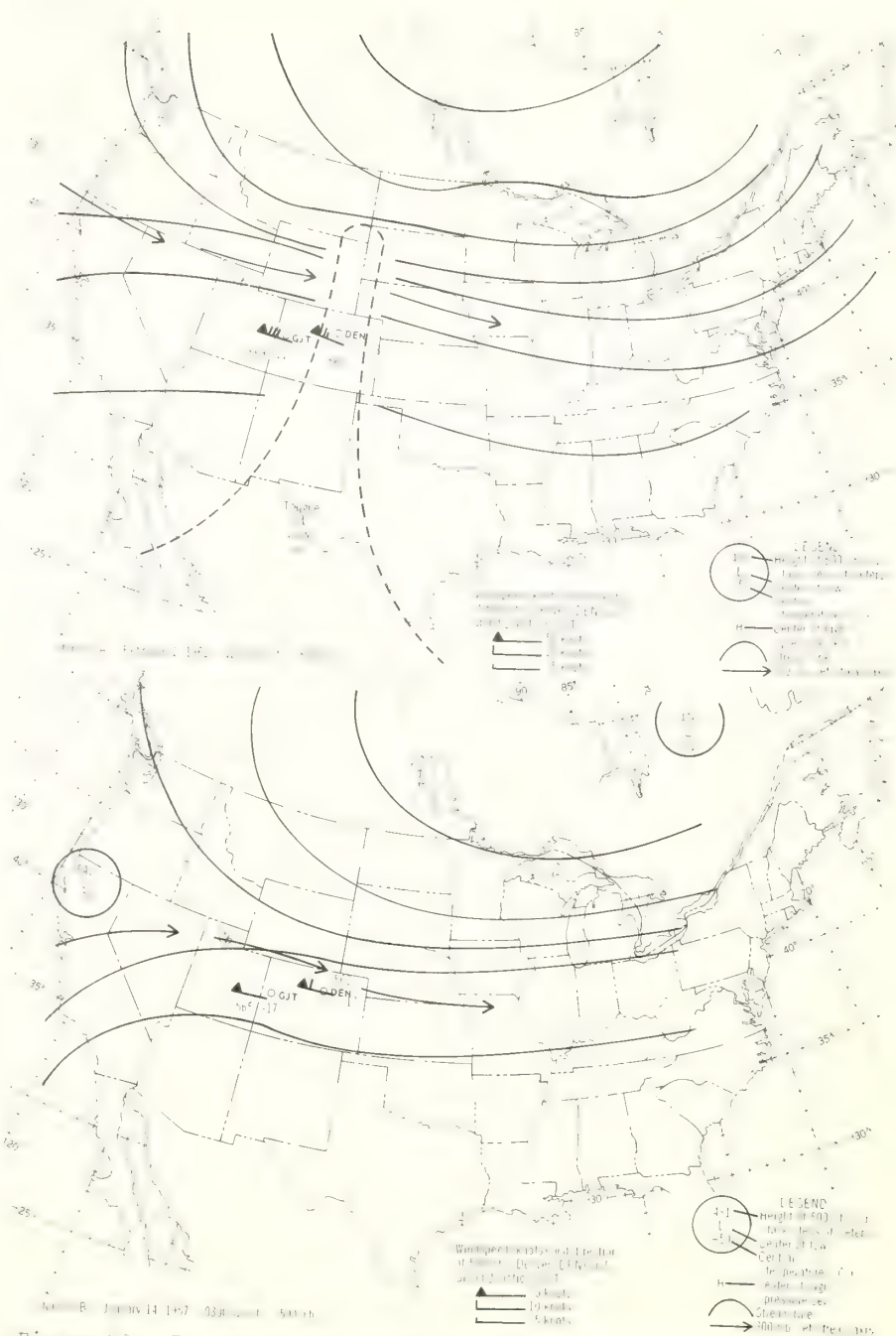
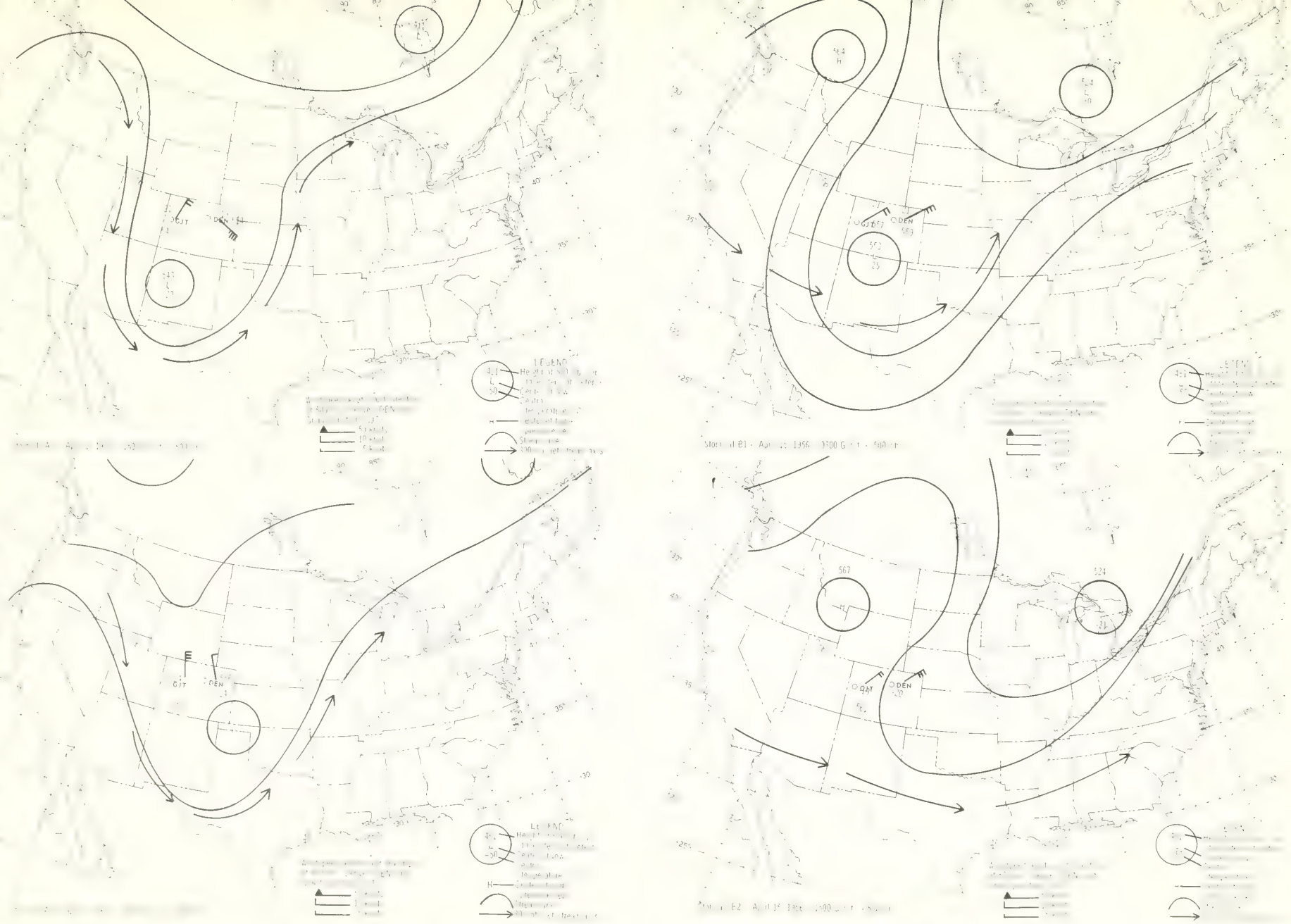


Figure 20.--Two storms of type II, each with four time sequences, Berthoud Pass, Colorado.



...northward.--... at type ... type III, 500 mi., with four time sequences for storm IIIA and ... for storm IIIB, Berthoud Pass, Colorado.

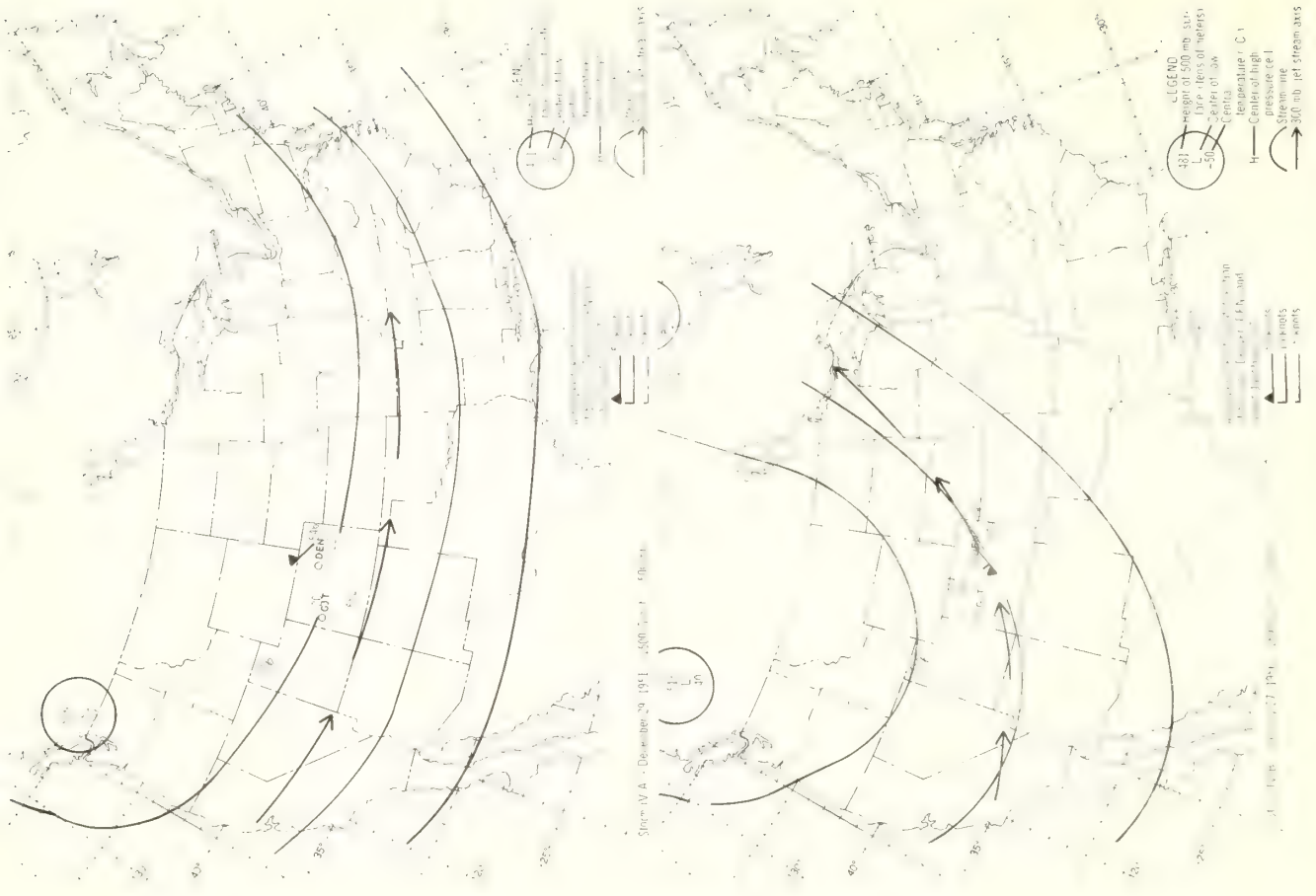


Figure 22.--Two storms of type IV, 500 mb., Berthoud Pass, Colorado

	500 mb. surface	
	Direction of flow over Colorado	Trough location or type
Storm type:		
I (fig. 19)	Northwest	East of Divide
II (fig. 20)	West	West of Divide, with convergence
III (fig. 21)	--	Closed low
IV (fig. 22)	West or southwest	West of Divide, without convergence

Arctic air flanked the east side of the Continental Divide in storm types I, II, and III, and may have served as a lifting mechanism that caused heavy precipitation in areas near the Divide. Types II, III, and IV reached their maximum intensity at the Pass while the upper trough was still west of the Divide. They diminished rapidly when the upper trough moved east of the Divide and the 500 mb. dewpoints northwest of the station became too low to measure.

The presence of the 300 mb. jet axis near or over northern Colorado, a distinct feature which accompanied all the storms except the cutoff cold lows in type III, was a contributing factor in the strong surface winds which occurred during each storm period. Half the precipitation fell while 6-hour windspeeds averaged more than 23 m.p.h. The proximity of the jet stream during periods other than those discussed also produced locally severe weather conditions above 10,000 feet m.s.l.

The 10 largest storms of the last 15 winters were ranked according to the amount of precipitation received in a 24-hour period (table 6).

Surface temperatures at Berthoud Pass averaged 20° F. warmer than those at 500 mb. during the four storm periods. The barograph traces at this station show a tendency to reflect the 500 mb. surface height changes during the major storms as well as for other periods.

Table 6.--Major storms at Berthoud Pass, 1950-64

Rank	Storm started	Water equivalent		Storm duration	Maximum 6-hour average windspeed and direction		Upper air map type
		Maximum 24-hour period	Storm total				
		Inches		Hours	M.p.h.		
1	Apr. 1, 1957	2.38	3.02	40	29	N	III
2	Dec. 28, 1951	1.70	3.20	72	(40)[1]	(NW)[1]	IV
3	Jan. 27, 1956	1.60	1.60	24	31	SW	IV
4	Jan. 29, 1963	1.47	2.85	97	49	SW	II
5	Mar. 24, 1955	1.33	1.43	28	34	W	I
6	Jan. 17, 1953	1.10	1.10	24	24	SW	I
7	Jan. 6, 1962	1.09	1.97	66	40	N	I
8	Apr. 14, 1956	1.05	1.05	16	22	SE	III
9	Feb. 11, 1956	1.00	1.31	38	25	NW	I
10	Jan. 12, 1957	.85	1.60	52	20	SW	II

[1] Estimated.

Type I Storms

During each of the four type I storms (fig. 19), a strong northwest jet over Denver appeared at the 300 mb. level. All 500 mb. maps showed a strong northwesterly flow over the Colorado Rockies, a trough in the lee of the Continental Divide, and a high off the California coast. In storms I-A, I-B, and I-C, a stationary arctic front flanked the east side of the Divide at the surface, but during storm I-D, there were no surface fronts within 800 miles of Berthoud Pass station.

Type II Storms

The two type II storms were accompanied by strong convergence at the 500 mb. level (fig. 20). At 300 mb., the jet axis was oriented west to east over Denver. Accompanying upper air features were a low center off the southern Oregon coast, a high over Alaska, and the usual well-developed Hudson Bay low. In both storms, arctic air at the surface flanked the east slope of the Rockies. Because stationary, primary, and secondary cold fronts were involved, storm II-A showed a more complex surface pattern than storm II-B.

The Pacific occlusion that passed the station on February 1, 1963, during storm II-A greatly intensified the storm already in progress. A strong southwesterly flow over California pumped a large quantity of moist, unstable air into the western mountain region. The presence of this airmass aloft in conjunction with the fast-moving Pacific occlusion produced 0.80 inch of water equivalent in a 6-hour period.

For storm II-A, the 500 mb. map shows a tongue of warm, moist air extending northward from Mexico to Montana. The phenomenon produced unusually high temperatures at the Pass, and caused the heaviest concentration of rime ice ever recorded at the station. Heavy rime ice conditions were widespread from 12,000 feet up, and were accompanied by a fall of high-density snow. A very unusual winter event in the Front Range was the rain recorded up to 10,800 feet m.s.l. during this February storm.

Type III Storms

Type III storms (fig. 21) are associated with the classical, closed low aloft that crosses southern Colorado from the southwest or west. Both storms of this type showed strong surface highs of about 1,030 mb. in southern Canada, and both reached peak intensity before the upper trough crossed the Continental Divide.

Storm III-A, on April 1-3, 1957, was the most intense winter storm recorded at the Berthoud Pass since 1949 (see table 6).[9]

The approach trajectory of storm III-A was unusual: the 500 mb. storm center entered the State of Washington from the Gulf of Alaska on March 31, (III-A1), then intensified and moved rapidly southward on the east side of a strong northerly jet (III-A2). The low reached a position over southern Utah on April 1, then moved slowly eastward to northwestern New Mexico on April 2 (III-A3), and crossed the

[9] The greatest recorded snowfall occurred in April 1933, when 94 inches of new snow fell in a 3-day period. Upper-air charts are not available, however, for this storm.

Continental Divide on April 3 (III-A4). A striking feature during this storm was the persistence of the strong meridianal components of the jet stream (III-A2, III-A3).

At the surface, a well-developed wave appeared in northeastern Arizona on April 1, and moved northeastward to Grand Junction on April 2 where it intensified. The low then moved east of the Divide on April 3.

At Berthoud Pass, storm III-A began at 0600 hours on April 1, and reached its peak near 0800 on April 2, while the upper trough was still west of the Divide. After the upper low crossed the Divide early on April 3, the storm was reduced to flurries.

Storm III-B, on April 15, 1956 (fig. 21) moved in from southern California, crossed the Divide swiftly, and though intense, lasted only 16 hours. At 300 mb., the jet exhibited a much stronger zonal component than storm III-A, and was partially responsible for the fast eastward movement of the storm center. After crossing the Divide, this storm, unlike III-A, opened up into a trough.

The surface low accompanying storm III-B formed at Grand Junction on April 15, on a West-to-east quasi-stationary front. The low then moved rapidly eastward across the Divide on April 16.

Type IV Storms

Each of the two storms in type IV (fig. 22) was accompanied by a strong westerly or southwesterly jet with its central axis across Grand Junction and Denver at the 300 mb. level. At 500 mb., a trough extended from northern Idaho southwestward to an area west of the California coast. A closed low was present over British Columbia, and a strong ridge of high pressure dominated Alaska. This combination produced a strong northerly flow from Alaska south over the Pacific to a point near the 40th parallel, where the upper winds showed a westerly or southwesterly component.

During storm IV-A, at the surface, the "Grand Junction low" formed on a stationary Pacific front, moved rapidly eastward, and crossed the Divide into southeastern Colorado. The upper trough associated with this storm did not cross the Divide until the storm at Berthoud Pass had ended. During storm IV-B, however, a surface low with a Pacific system crossed north of the station.

PERIOD II: SPRING-FALL (MAY 1 - OCTOBER 31)

Continuous records of precipitation and temperature for this period were begun at Berthoud Pass in July 1961; wind, in May 1963 (see appendix, table 7).

May

Nearly all of the precipitation in May falls in the form of snow. Thunder and lightning occasionally accompany the snowfall, and upslope fogs are common in the postfrontal sector. The seasonal snowpack is isothermal, and alternately undergoes surface freezing at night and melting during the day. Maximum temperatures run between 35° F. and 50° F., while minimums usually range from 15° F. to 30° F. Severe winter-type storms are infrequent. Maximum average hourly windspeeds seldom exceed 35 m.p.h.

June

The thunderstorm season begins in June, with clear mornings and afternoon showers. Small amounts of snow fall occasionally, usually as flurries. The snowpack generally disappears during the third week. Temperatures are mild--between 30° F. and 60° F. Light winds prevail, except during thunderstorms. Peak hourly windspeeds seldom exceed 30 m.p.h.

July-August

Frequent afternoon thundershowers of rain, graupel, and small hail provide most of the precipitation. Intense lightning makes the operation of exposed instruments, above timberline, difficult and expensive. Precipitation intensities are low; 1-hour amounts rarely ex-

ceed 0.50 inch. The maximum 1-hour amount on record was 0.95 inch. Temperatures usually range from 35° F. to 65° F. but occasionally drop to freezing. Peak hourly windspeeds seldom exceed 20 m.p.h.

September-October

Thunderstorm activity declines, and clear, dry weather interspersed with some weak frontal activity is common. Most precipitation falls as snow, with moderate rime ice occurring above 12,000 feet m.s.l. Large, winterlike storms, although infrequent, have been recorded in both months. Upslope fogs following cold fronts commonly funnel through the Pass. Temperatures range from 15° F. to 65° F. Winds increase, with peak hourly speeds of 30 m.p.h. or greater.

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APPENDIX -- BASIC DATA

Summary of meteorological data . . . . . Table 7

Precipitation . . . . . Tables 8, 9, 10; Figures 23, 24

Snow depth . . . . . Tables 11, 12

Wind . . . . . Tables 13, 14; Figures 25, 26

Temperature . . . . . Table 15

Table 7.--Summary of meteorological data at Berthoud Pass, Colorado, 1950-64

Meteorological data	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature[1] (Degrees F.):													
Mean	11	12	16	24	37	44	51	48	41	32	19	12	29
Maximum	40	42	49	56	61	68	72	72	65	61	51	41	72
Minimum	-28	-35	-20	-4	4	21	21	25	4	2	-25	-23	-35
Precipitation[2] (Inches):													
Mean	3.30	3.34	3.81	4.15	2.48	2.09	2.21	3.21	2.76	1.55	2.45	3.47	34.82
Maximum[3]	6.07	4.77	5.85	9.89	7.10	3.35	4.85	6.20	5.32	4.70	4.50	7.27	45.49
Minimum	1.13	2.08	1.09	1.61	.89	1.24	.47	.92	1.19	.49	.62	.88	25.46
Snowfall[4] (Inches):													
Mean	51	49	53	53	30	2	.5	[5] T	14	19	38	52	361.5
Maximum[6]	93	72	79	122	71	9	8	2	72	47	70	81	518
Minimum	19	26	16	19	2	0	0	0	0	3	11	16	267
Windspeed[7] (Miles per hour):													
Mean	16	15	16	15	13	11	10	10	10	11	14	16	13
Maximum:													
1 minute	--	--	--	--	--	--	--	--	--	--	--	95	95
1-hour average	55	--	--	--	--	--	--	--	--	--	--	53	55
6-hour average	49	38	40	40	--	--	--	--	--	--	38	47	49

[1] May-October: May 1962-64; June 1957, 1962-64; July-Aug. 1957, 1961-64; Sept. 1961-64; Oct. 1949, 1961-64.
[2] May-October: May 1950, 1957, 1962-64; June-Aug. 1957, 1961-64; Sept.-Oct. 1959, 1961-64.
May and October values were estimated, using average density values for the maximum recorded snowfall for these months.
[4] May-October: Adjusted, using 1931-39 average with May 1950, 1957, 1962-64; June 1963-64; July 1961, 1963-64; Aug. 1962-64; Sept.-Oct. 1957, 1959, 1961-64.
[5] Trace.
[6] Exceeded earlier on: Jan. 1936--101 inches; Feb. 1934--128 inches; Mar. 1932--141 inches; Apr. 1933--154 inches.
[7] May-October: 1963-64 only.

Table 8.--Monthly and seasonal snowfall at Berthoud Pass, Colorado, 1926-39 (data taken by Clyde E. Learned)

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Total
						Inches							
1926-27	6	20	77	56	41	84	--	--	--	--	--	--	--
1928-29	--	21	42	31	--	--	--	--	--	--	--	--	--
1931-32	0	12	39	21	47	43	141	71	29	0	--	--	403
1932-33	2	41	47	52	63	33	65	154	50	0	--	--	507
1933-34	6	4	8	29	26	128	66	21	30	0	--	--	318
1934-35	8	3	54	58	26	28	57	128	71	6	--	--	439
1935-36	7	47	41	45	101	95	69	21	35	2	6	--	469
1936-37	23	25	21	46	43	76	59	50	10	9	--	--	362
1937-38	14	35	72	64	55	19	63	73	37	0	--	--	432
1938-39	0	4	45	60	48	69	80	55	15	0	--	--	376
1931-39:													
Mean	8	21	41	47	51	61	75	72	35	2	413 (Total)		
Extremes:													
Maximum	23	47	72	64	101	128	141	154	71	9	507 (1932-33)		
Minimum	0	3	8	21	26	19	57	21	10	0	318 (1933-34)		

Table 9.--Monthly and seasonal snowfall at Berthoud Pass, Colorado, 1949-64

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
						Inches						
1949-50	--	26	11	16	46	36	33	27	[1](28)	--	--	--
1950-51	--	--	(70)	50	29	45	16	56	--	--	--	--
1951-52	--	--	(40)	81	40	43	43	58	--	--	--	--
1952-53	--	--	(28)	45	80	47	50	(50)	--	--	--	--
1953-54	--	--	(54)	47	19	33	61	(19)	--	--	--	--
1954-55	--	--	(41)	29	38	26	71	(35)	--	--	--	--
1955-56	--	--	(66)	63	90	62	36	(64)	--	--	--	--
1956-57	--	--	(33)	44	93	43	79	[2](122)	(54)	--	--	--
1957-58	(3)	(7)	38	79	53	72	75	66	--	--	--	--
1958-59	--	--	(30)	71	51	72	56	36	--	--	--	--
1959-60	36	31	30	16	42	67	72	32	--	--	--	--
1960-61	--	--	22	46	25	36	57	64	--	--	8	--
1961-62	72	26	33	54	63	50	33	74	(24)	--	--	2
1962-63	3	(5)	26	40	57	64	47	23	2	9	0	0
1963-64	[3]T	8	16	41	34	38	61	68	19	9	0	2
Winter (November-April):												
Mean			36	48	50	49	53	53	289 (Total)			
Extremes:												
Maximum			70	81	93	72	79	122	414 (1956-57)			
Minimum			16	16	19	26	16	19	169 (1949-50)			

[1] Part or all of entries in parentheses were based on average density values of new snowfalls.
[2] 102 inches actually recorded April 1-13, 1957; last 20 inches based on average new snowfall density values. [3] Trace.

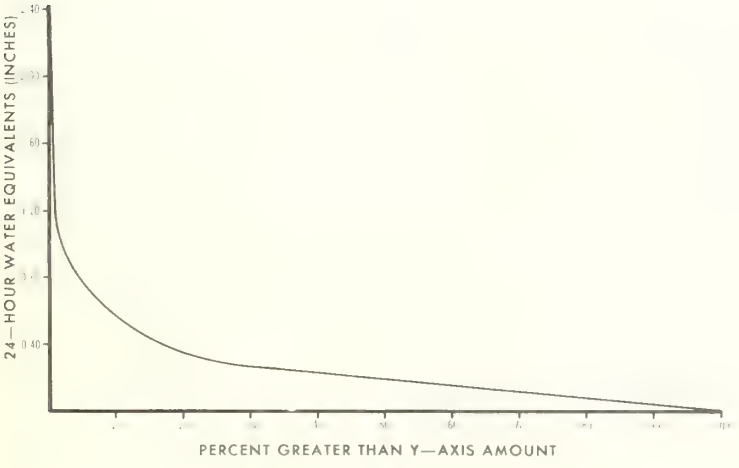


Figure [illegible].--Frequency distribution of the 24-hour water equivalents of the new snowfalls at Berthoud Pass, November - April 1949-64 (1,011 storms).

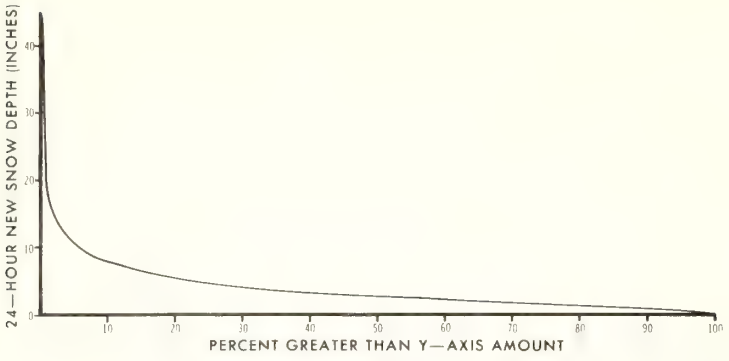


Figure 24.--Frequency distribution of the 24-hour new snow depths at Berthoud Pass, November - April 1931-39 and 1949-64 (1,420 entries).

Table 10.--Monthly precipitation at Berthoud Pass, Colorado, 1949-64

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
						Inches of water						
1949-50	--	2.45	0.62	1.19	2.76	2.08	2.96	2.21	2.64	--	--	--
1950-51	--	--	[1](4.35)W	(3.09)W	1.99	3.32	1.09	6.77	--	--	--	--
1951-52	--	--	(2.43)W	7.27	3.19	3.16	3.42	5.08	--	--	--	--
1952-53	--	--	(1.71)W	3.50	5.98	3.49	3.83	(3.50)	--	--	--	--
1953-54	--	--	(3.80)L	3.04	1.13	2.45	4.73	(1.61)	--	--	--	--
1954-55	--	--	(2.70)L	2.09	2.67	2.28	5.40	(2.28)	--	--	--	--
1955-56	--	--	(4.50)L	3.77	5.62	4.06	2.10	(5.13)L	--	--	--	--
1956-57	--	--	(2.35)W	2.99	6.07	3.07	5.61	9.89	5.10	1.24	0.47	3.98
1957-58	(1.72)W	(2.30)W	1.87	4.17	2.67	4.77	5.85	4.86	--	--	--	--
1958-59	--	--	(1.75)L	4.59	3.59	4.32	4.11	2.71	--	--	--	--
1959-60	[2](3.24)	2.97	2.06	.88	2.20	4.51	4.63	2.45	--	--	--	--
1960-61	--	--	1.50	2.75	1.42	2.15	3.76	5.33	--	1.70	4.85	3.76
1961-62	5.32	1.65	2.26	3.71	3.91	3.67	2.00	4.62	2.24	2.30	.96	.92
1962-63	1.24	.49	1.27	1.84	4.04	4.13	3.12	1.85	.89	3.35	2.09	6.20
1963-64	2.82	.97	1.31	2.66	2.25	2.67	4.47	4.03	1.69	1.87	2.70	1.19
Winter (November-April):												
Mean			2.30	3.17	3.30	3.34	3.81	4.15	20.07 (Total)			
Extremes:												
Maximum			4.50	7.27	6.07	4.77	5.85	9.89	29.98 (1956-57)			
Minimum			.62	.88	1.13	2.08	1.09	1.61	11.82 (1949-50)			

[1] Part or all of entries in parentheses were estimated by the ratio method from Winter Park data (W) and Loveland Basin data (L).
[2] Approximated by using average density value for a known amount of snowfall.

Snow depth

Table 11.--Maximum monthly snow depths at Berthoud Pass, Colorado, October-May 1931-64

Season	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Season	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
				Inches									Inches				
1931-32	--	12	24	48	68	97	94	55	1948-49	6	21	60	61	70	85	94	--
1932-33	--	25	43	54	78	106	[1]174	130	1949-50	14	14	22	43	57	74	82	--
1933-34	--	--	15	17	88	96	52	42	1950-51	--	--	--	66	80	92	115	--
1934-35	--	24	52	65	70	83	118	110	1951-52	--	24	72	74	87	94	101	--
1935-36	24	26	40	85	119	123	128	96	1952-53	--	--	28	48	58	67	72	--
1936-37	6	19	38	47	72	80	86	58	1953-54	--	--	38	37	44	60	56	--
1937-38	19	26	38	61	64	81	100	104	1954-55	--	--	30	43	53	73	76	--
1938-39	2	23	53	70	82	96	109	--	1955-56	--	28	48	64	74	70	83	--
1939-40	4	--	--	--	--	--	--	--	1956-57	--	24	34	58	61	72	108	95
1940-42	--	--	--	--	--	--	--	--	1957-58	--	24	46	55	71	86	95	--
1942-43	--	--	59	60	69	86	95	--	1958-59	--	19	42	52	73	81	83	--
1943-44	--	25	34	43	56	68	94	--	1959-60	--	36	40	54	73	93	87	--
1944-45	--	12	24	39	55	74	--	--	1960-61	--	16	34	41	49	60	76	70
1945-46	10	26	56	60	75	76	--	--	1961-62	26	33	44	64	77	79	90	72
1946-47	11	19	31	36	62	80	110	--	1962-63	2	10	20	36	55	60	52	35
1947-48	16	30	34	62	66	84	94	--	1963-64	6	10	31	32	47	67	72	64

[1] Occurred on April 22, 1933.

Table 12.--Snow depths[1] at Berthoud Pass, Colorado, taken from daily readings, November-April 1942-64

Season	November				December				January				February				March				April			
	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum
	Inches																							
1942-43	--	--	--	--	--	40	--	59	60	53	46	60	59	64	59	69	69	85	69	86	75	92	75	95
1943-44	--	11	5	25	23	24	22	34	38	30	30	43	43	54	43	56	56	55	55	68	68	76	64	94
1944-45	—	6	--	12	12	20	12	24	24	36	24	39	39	49	39	55	54	64	54	74	74	--	54	--
1945-46	10	17	10	26	25	36	26	56	55	54	53	60	55	70	55	75	74	67	65	76	64	66	--	--
1946-47	11	15	11	19	19	29	19	31	31	36	29	36	34	42	34	62	62	59	59	80	80	109	80	110
1947-48	16	11	16	30	30	30	30	34	38	42	38	62	59	57	55	66	66	72	66	84	80	74	68	94
1948-49	6	15	6	21	21	32	21	60	60	51	51	61	58	67	59	70	70	84	79	85	83	85	--	94
1949-50	12	14	4	14	10	14	8	22	16	25	16	43	44	48	43	57	56	58	52	74	77	72	64	82
1950-51	--	--	--	--	--	--	--	--	--	39	--	66	46	76	60	80	73	84	73	92	91	105	--	115
1951-52	--	--	--	24	22	35	22	72	69	55	55	74	70	72	69	87	75	79	75	94	95	90	75	101
1952-53	--	--	--	--	--	21	10	28	28	36	28	48	44	52	44	58	50	53	50	67	65	72	—	72
1953-54	--	--	--	--	--	31	21	38	31	32	29	37	34	35	32	44	44	47	43	60	56	41	--	56
1954-55	--	--	--	--	23	25	22	30	28	34	28	43	42	45	42	53	53	69	49	73	68	69	--	76
1955-56	--	26	--	28	24	30	24	48	37	47	33	64	59	72	56	74	65	70	63	70	63	79	—	83
1956-57	--	17	11	24	17	31	17	34	30	54	30	58	50	50	48	61	62	65	58	72	66	100	--	108
1957-58	6	18	6	24	23	29	22	46	41	39	36	55	54	63	51	71	62	75	61	86	82	85	80	95
1958-59	--	6	0	19	18	40	18	42	34	39	34	52	52	48	48	73	70	73	68	81	74	77	69	83
1959-60	--	27	--	36	34	33	32	40	38	50	38	54	48	66	48	73	74	93	74	93	87	67	58	87
1960-61	--	13	—	16	16	21	16	34	30	36	29	41	36	38	36	49	48	50	46	60	61	72	58	76
1961-62	21	29	21	33	40	35	33	44	56	63	46	64	67	67	59	77	--	77	67	79	88	88	61	90
1962-63	0	2	0	10	6	11	6	20	17	22	17	36	37	40	37	55	54	53	48	60	48	39	33	52
1963-64	6	5	4	10	8	17	8	31	25	28	23	32	30	37	30	47	44	52	43	67	60	69	59	72
Total	88	232	94	371	371	584	389	827	786	901	713	1128	1060	1212	1047	1412	1281	1484	1317	1681	1605	1627	898	1735
Mean	10	14	8	22	21	28	19	39	37	41	34	51	48	55	48	64	61	67	60	76	73	77	64	87

[1] Readings December 1942 to April 1951 taken at Bowl behind lodge, November 1951 to April 1964 at Q-12 Park.

Wind

Table 13.--Average monthly windspeeds at Berthoud Pass, Colorado, 1949-64

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
	Miles per hour											
1949-50	--	--	6	6	10	6	8	6	--	--	--	--
1950-51	--	--	--	--	--	6	--	--	--	--	--	--
1951-52	--	--	--	7	8	[1] 14	14	10	--	--	--	--
1952-53	--	--	--	--	19	17	16	([2])	--	--	--	--
1953-54	--	--	--	16	15	([2])	--	--	--	--	--	--
1954-55	--	--	--	13	16	16	18	([2])	--	--	--	--
1955-56	--	--	([2])	17	12	13	17	([2])	--	--	--	--
1956-57	--	--	([2])	([2])	16	14	17	([2])	--	--	--	--
1957-58	--	--	--	([2])	([2])	([2])	([2])	([2])	--	--	--	--
1958-59	--	--	--	--	([2])	--	--	--	--	--	--	--
1959-60	--	--	--	--	16	14	17	([2])	--	--	--	--
1960-61	--	--	--	([2])	([2])	15	15	([2])	--	--	--	--
1961-62	--	--	([2])	17	15	16	15	14	--	--	--	--
1962-63	--	--	15	15	17	17	16	17	13	10	10	9
1963-64	10	10	12	15	16	15	15	17	13	12	10	11

[1] Anemometer moved from 11,314 feet m.s.l. to 11,880 feet m.s.l.
[2] Data available, but for less than a full month.

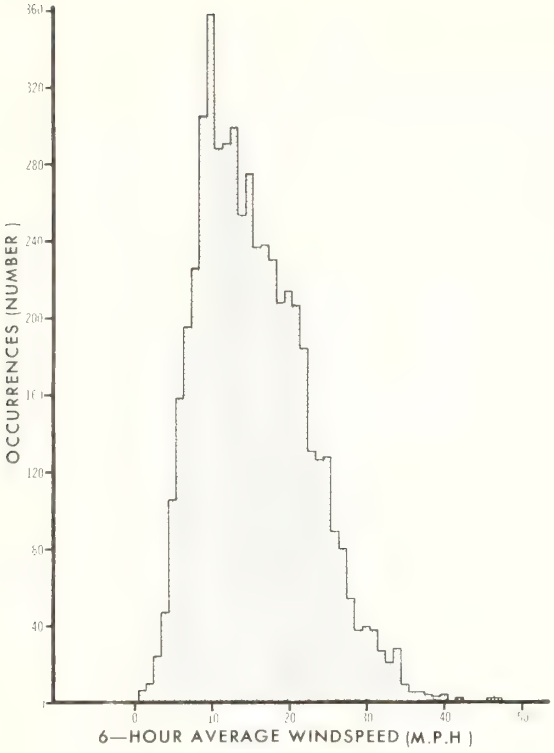
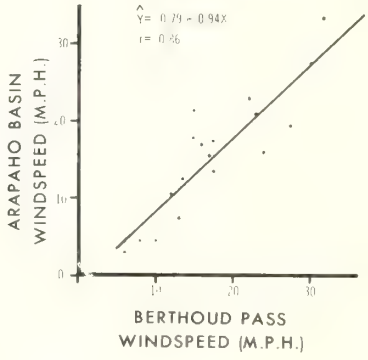


Figure 25.--Distribution of the six-hour average windspeeds (m.p.h.) at Berthoud Pass, Colorado; November - April 1951-63 (Mean = 16; Median = 15; Mode = 10).

Table 14.--The 20 greatest recorded 6-hour average windspeeds at Berthoud Pass, Colorado, with associated weather factors

Direction	6-hour average-- Windspeed	Temperature	Precipitation	Pressure	Date	6 hours ending at--
	M.p.h.	°F.	Inches	Inches of mercury		
SW	47	34	0	19.66	Dec. 24, 1955	1200
SW	46	28	.23	19.67	Jan. 31, 1963	2400
SW	42	33₂	0	19.60	Dec. 24, 1955	0600
NW	42	14	.20	19.56	Dec. 7, 1957	1200
NE	40	2	0	19.52	Mar. 23, 1957	1800
S	40	25	0	19.38	Jan. 20, 1957	1800
NW	40	19	.17	19.52	Apr. 7, 1962	1800
NW	40	15	.01	19.71	Apr. 13, 1964	2400
N	40	12	.25	19.73	Jan. 8, 1962	0600
S	39	25	0	19.46	Mar. 12, 1964	1200
NW	39	2	0	19.20	Mar. 16, 1963	0600
SW	39	2	.18	19.43	Jan. 11, 1955	2400
NW	38	5	.22	19.67	Dec. 21, 1961	2400
S	38	32	0	19.60	Nov. 21, 1955	1200
SW	38	32	.40	19.58	Feb. 1, 1963	1200
SW	38	42	0	19.64	Mar. 28, 1963	1800
W	37	-7	.02	19.44	Jan. 26, 1963	1200
NW	37	21	0	19.58	Dec. 13, 1955	0600
SW	37	35	0	19.52	Dec. 23, 1955	2400
SW	37	14	0	19.50	Dec. 18, 1955	0600

Figure 26.--Correlation of 15-hour average windspeeds (m.p.h.) between Berthoud Pass and Arapaho Basin, January - April 1963.



Temperature

Table 15.--Average monthly temperatures at Berthoud Pass, Colorado, 1949-64

Season	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
	Degrees F.											
1949-50	--	29	29	13	12	16	17	28	--	--	--	--
1950-51	--	--	--	--	[1] 12	16	15	[1] 22	--	--	--	--
1951-52	--	--	--	6	7	6	8	23	--	--	--	--
1952-53	--	--	--	[1] 8	13	7	20	[1] 15	--	--	--	--
1953-54	--	--	--	[1] 8	16	18	16	[1] 30	--	--	--	--
1954-55	--	--	--	12	8	6	17	[1] 22	--	--	--	--
1955-56	--	--	[1] 14	16	15	7	15	[1] 19	--	--	--	--
1956-57	--	--	14	13	11	20	17	[1] 20	--	[1] 42	50	49
1957-58	--	--	13	14	11	17	15	22	--	--	--	--
1958-59	--	--	[1] 19	17	12	13	15	25	--	--	--	--
1959-60	--	--	[1] 19	14	9	5	19	27	--	--	--	--
1960-61	--	--	[1] 18	12	12	12	17	21	--	--	45	45
1961-62	32	28	17	8	9	15	14	29	35	44	51	52
1962-63	45	34	25	16	8	16	18	26	39	46	54	49
1963-64	46	40	24	12	8	5	12	24	36	42	54	47

[1] Data include 15 days or more, but less than a full month.

Agriculture - - CSU, Ft. Collins

Judson, Arthur.
1965. The weather and climate of a high mountain pass in the Colorado Rockies. U. S. Forest Serv. Res. Paper RM-16, 28 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Presents information basic to mountain meteorology and avalanche-control planning from Berthoud Pass -- an area representative of Colorado's avalanche zones near timberline. Describes and illustrates wind, temperature, snowfall, snow depth, rainfall, and related weather patterns from data collected irregularly 1926-49, continuously since then. Compares direction and windspeeds at surface at Berthoud Pass with 4,000 m. winds over Denver and Grand Junction. Analyzes weather relationships of 10 large winter storms at the Pass.

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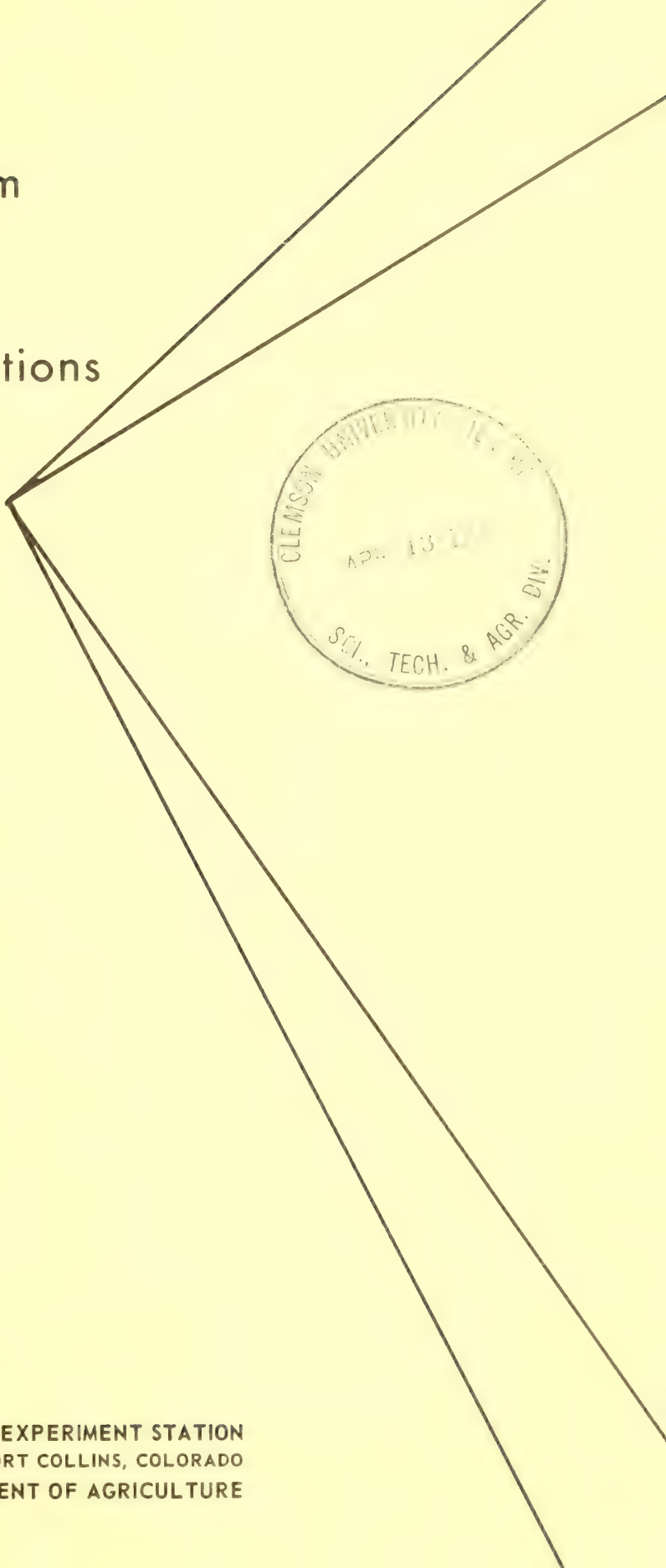
An Inventory System for Multiple Use Evaluations



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Peter F. Ffolliott
David P. Worley

U. S. Forest Service
Research Paper RM-17

December 1965

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
RAYMOND PRICE, DIRECTOR FORT COLLINS, COLORADO
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-17 December 1965

AN INVENTORY SYSTEM FOR MULTIPLE USE EVALUATIONS

by

Peter F. Ffolliott, Associate Silviculturist

and

David P. Worley, Principal Economist

Rocky Mountain Forest and Range Experiment Station[1]

[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins; authors are located, respectively, at Flagstaff in cooperation with Arizona State College and at Tempe in cooperation with Arizona State University.

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An Inventory System for Multiple Use Evaluations

by

Peter F. Ffolliott and David P. Worley

INTRODUCTION

The management of many tracts of forest land is based on principles of multiple use and sustained yield. Managers of such lands have available research results which show the product yields of the various multiple uses for different forest conditions and land productivity. More of this type of information is becoming available. This background data should help managers understand and evaluate proposed land management practices on their own lands in multiple use terms. Often, though, the research data are of limited use to managers because the land is not inventoried to take advantage of these findings in a variety of fields.

This paper describes a multiple BAF (basal area factor) inventory system that is flexible enough to describe a forested tract so multiple use interpretations can be made from known relations of product yields to the inventory description of the resources on the tract. Basal area was selected as the inventory basis because it is: (1) easily determined in the field; (2) easily converted to other expressions; and (3) many multiple use relations have already been developed with basal area as the independent variable. A multiple BAF system is a point-sampling system that uses several basal area factors to describe the stocking of trees. Its use is illustrated by hypothesizing forest management methods for one of the Beaver Creek pilot watersheds in Arizona. [2]

Known relations of different products to forest conditions are blended with inventory data (1) to determine if it is feasible to manage the land as proposed; (2) to determine what changes in multiple use production can be expected; and (3) to estimate the immediate direct costs and returns associated with change in management.

[2] A 278,000-acre watershed on the Coconino National Forest where costs and benefits of intensive multiple-use land management are being evaluated as a part of the Arizona Watershed Program.

DESCRIPTION OF METHOD

To be effective, an inventory must provide the land manager with information:

1. On the portions of an area stocked to different levels of stocking. Stocking, as used here, is a measure of occupancy of growing space by different classes of trees.

2. On the portions of an area stocked with trees exhibiting specific characteristics. These tree characteristics must be related to different parameters required in multiple use evaluation.

3. On the feasibility of treating an area to attain desired stocking conditions specified by multiple use objectives. The land manager must be able to determine whether it is rational to put a particular treatment on an area.

4. For describing the overstories on different areas on a standardized basis.

Principles of Method

In essence, the inventory method involves point-sampling techniques. Points are considered either not stocked or stocked to a particular basal area level. If no trees are recorded, a point is not stocked at the given basal area level. A point is stocked at the given basal area level if at least one tree is tallied.

Point samples are located on an area to give a "representative" sample. Each point is described as not stocked or stocked to each at several basal area stocking levels. The number of points that are stocked to a given level can be determined and expressed as a percent of the total number of point samples on an area. The percent of the area stocked, or not stocked, can be determined by any sampling method that provides a representative sample of the area.

The relationship between stocking at different basal area levels is found by using more than one BAF to determine stocking at a point. Stocking conditions on an area can then be expressed in terms of percent of the area not stocked or stocked to different basal area stocking levels. It is then possible to decide on the feasibility of carrying out a particular type of management. For example, the stocking conditions at 50 square feet basal area stocking level on an area could be not stocked, 15 percent of the area; stocked, 85 percent of the area. A proposed management prescription could be to thin the overstory to 50 square feet basal area. What percent of the area will meet management specifications following treatment?

Since 85 percent of the area is stocked at a basal area level of 50 square feet, this will be the percent of the area that will meet management specifications. The 15 percent not stocked at 50 square feet will not meet the stocking requirements outlined in the prescription.

The presence or absence of specific characteristics are recorded for the trees tallied at the point samples. The occurrence of a particular characteristic is then determined within an area, and allows for describing the percent of an area not stocked or stocked with trees exhibiting this characteristic at different basal area stocking levels.

Development of Method

An overstory inventory based on the principles discussed above was developed to meet the particular stocking conditions on Beaver Creek. The overstory on Beaver Creek can be described as "cutover" ponderosa pine with intermingling Gambel oak and alligator juniper. All size classes are included. The adaptation of the method as applied to Beaver Creek was designed to measure these conditions specifically.

Basal Area Stocking Levels

The basal area stocking levels used in this inventory were 25, 50, and 75 square feet. These basal area levels appeared to be rational levels for management on Beaver Creek. Two approaches were followed to determine if a point is not stocked or stocked for each of the basal area stocking levels.

An angle gage was used to tally trees 7.0 inches d.b.h. and larger. The BAFs used were 25, 50, and 75, corresponding to the three basal area stocking levels. A point was not stocked at a basal area level of 25 square feet with trees 7.0 inches d.b.h. and larger if no trees of this size were tallied with the angle gage at a BAF of 25. A point was stocked at a basal area level of 75 square feet if at least one tree was tallied with the angle gage at a BAF of 75.

The smaller size classes in ponderosa pine occur in clumps. Existing basal area levels under these conditions are not desirable. Therefore, fixed-size plots were used for tallying trees smaller than 7 inches d.b.h. The size of these plots was determined from growing-space requirements for the number of trees per acre necessary to attain the basal area when the stand reaches 10 inches d.b.h. These data are based on proposed ponderosa pine stand structures necessary to sustain production at different basal area levels when the stand reaches 10 inches d.b.h. (table 1).

Three fixed-size plots for each basal area level were used to simplify field measurements. The three plots included a plot for the small pole size class (4 to 6 inches d.b.h.), the sapling size class (1 to 3 inches d.b.h.), and reproduction (1 to 4-1/2 feet in height).

It was necessary to determine the average number of trees per acre needed in a size

Table 1.--Stand structures to sustain production at different prospective basal area levels[1]

Diameter breast height (inches)	Basal area level of--					
	25 square feet per acre		50 square feet per acre		75 square feet per acre	
	Trees per acre	Basal area	Trees per acre	Basal area	Trees per acre	Basal area
	No.	Sq.ft.	No.	Sq.ft.	No.	Sq.ft.
1	208	1.64	415	2.26	623	3.12
2	175	3.85	350	7.64	525	11.55
3	150	7.35	300	14.73	450	22.05
4	126	10.96	252	22	378	33
5	106	14	213	29	319	43
6	92	18	183	36	275	53
7	76	20	153	41	229	61
8	66	22	132	46	198	68
9	55	24	111	49	167	74
10	46	25	92	50	138	75

[1] Adapted from Myers, Clifford A., Methods of cutting ponderosa pine in the Southwest. 29 pp., App. I-IV. (Study plan on Timber Management Project FS-RM-1203.10, submitted June 20, 1961; on file at Rocky Mountain Forest & Range Exp. Sta., U.S. Forest Serv., Ft. Collins, Colo.)

class to compute the radius of the fixed-size plots. The average was obtained by totaling the number of trees in each d.b.h. class represented in the size class (table 1), and dividing by the number of d.b.h. classes in the size class. The computations are summarized in table 2.

It is important to remember that stocking by these smaller size classes is to a "prospective" basal area level. "Prospective" stocking will become existing stocking when the stands reach 10 inches d.b.h. if the stands on Beaver Creek are placed under management as prescribed by the proposed stand structures.

Table 2.--Determination of plot radius for the fixed-size plots

Size class[1]	Basal area level	Trees per acre	Area required per tree[2]	Plot radius[3]
	Sq.ft./acre	No.	Sq.ft.	Ft.
Reproduction (1-4½ ft. height)	25	208	209.4	8.1
	50	415	105.0	5.8
	75	625	69.7	4.7
Saplings[4] (1-3 in. d.b.h.)	25	175	248.9	8.9
	50	355	122.7	6.2
	75	533	81.7	5.1
Small poles[4] (4-6 in. d.b.h.)	25	100	435.6	11.8
	50	200	217.8	8.3
	75	300	145.2	6.8

[1] Refers to diameter range; not to specific products.
[2] 43,560 divided by number of trees per acre.
[3] $\sqrt{\frac{\text{Area per tree}}{3.1416}}$
[4] Saplings measured by 1-inch classes; poles and sawtimber, by 2-inch classes.

The procedure followed in determining whether a point is not stocked or stocked to a "prospective" basal area level was similar to the angle gage tally. A point was not stocked with small poles at a "prospective" basal area level of 25 square feet if no small poles were counted in the appropriate fixed-size plot. A point was stocked with saplings at a "prospective" basal area level of 75 if at least one sapling was tallied in the proper fixed-size plot.

Procedure for Tallying Trees at a Point

The procedure followed in tallying trees at a point is summarized by the following steps:

1. Tally trees stocking a point to a basal area level of 25 square feet. Tree number 1 will be the first tree tallied; tree number 2 the second tallied, etc.
   a. Count all trees 7 inches d.b.h. and above with the angle gage at a BAF of 25. Tally in a fixed pattern, to be carried out on all points.
   b. Count the small poles on the appropriate fixed-size plot.
   c. Count all saplings.
   d. Count all reproduction.

2. Tally trees stocking a point to a basal area level of 50 square feet. These trees will already be tallied for the 25-square-foot level.

3. Tally trees stocking a point to a basal area level of 75 square feet. These trees will have been tallied above.

Individual measurements were made on the trees tallied to determine stocking to a basal area level of 25 square feet. To eliminate bias, specific trees were selected in advance for measuring total height and annual ring count. The measurements made in this inventory were of particular interest on Beaver Creek since it was desired to determine treatment feasibility and timber values. Many

additional measurements could have been included if desired.

The individual tree measurements made are listed below:

1. Species.
2. D.b.h.
3. Total height--taken on only the first tree tallied to determine stocking to a basal area level of 25 square feet.
4. Annual ring count--increment boring made on same tree measured for total height.
5. Crown position.
6. Biotic injury:
   a. Dwarfmistletoe.
   b. Insect damage.
   c. Disease damage.
7. Mechanical injury:
   a. Fire scars.
   b. Lightning scars.
   c. Damaged top--broken, dead, etc.
8. Form characteristics:
   a. Sweep.
   b. Crook.
   c. Lean.
   d. Fork.
9. Knot configurations:
   a. Number of clear faces.
   b. Number of knots.
   c. Size of knots.

Points were considered not stocked to a basal area level if no trees were tallied at the point by means of the corresponding basal area measurements. A point not stocked was recorded as (a) can be stocked naturally or artificially, or (b) cannot be stocked naturally or artificially (rocks, water, etc.). These latter points were considered "nonstockable."

Topographic information was also taken during the inventory. The aspect and slope percent were measured at each point. The area sampled can be characterized by steepness and aspect relations from these measurements.

Sample Design

An important requirement in sample design is that a "representative" sample be obtained. A systematic sample design may be used, or, if measurements of variation are wanted, a systematic sample with multiple random starts (Freese 1962, Shiue 1960)[3] can be followed.

The point samples should be located at regular intervals along lines running across the area sampled, regardless of the sample design applied. This is important because many of the characteristics tallied can be mapped, and a regular pattern facilitates mapping. The interval between point samples and the number of lines depends on the intensity of sampling desired.

Computations

Individual point samples are described in terms of each basal area stocking level as follows:

1. Not stocked.
2. Stocked.
3. If not stocked:
   a. Can be stocked naturally or artificially.
   b. Cannot be stocked naturally or artificially.

If each point sample is considered as a sample unit, the area inventoried can be described as follows:

1. Percent of the area not stocked at each basal area level.
2. Percent of the area stocked.

If an area is stocked at a particular basal area level, trees exhibiting different individual characteristics can be segregated. Then, the percent of the area stocked at the basal area level by trees of different characteristics can be determined.

The relationships between the percent of the area not stocked and stocked at the three basal area levels are determined. These relationships can be represented by regressions, and the equations for the regressions considered stocking equations. It is possible to

[3] *Names and dates in parentheses refer to Literature Cited, p. 14.*

determine the percent of the area not stocked or stocked at basal area levels between those used in the inventory from these stocking equations.

Linear regressions were developed from the three BAFs used in this inventory. Regressions for particular size classes, or for BAFs near the extremes for the whole populations, may require a curvilinear form. BAFs would have to be used to develop the proper form of the relationship.

The following stocking equation describes the percent of the area not stocked with ponderosa pine (all size classes):

$Y = -5.0 + 0.4X$

Y = percent of area not stocked with ponderosa pine

X = any basal area level between 25 and 75 square feet

What percent of the area is not stocked with ponderosa pine at 40 square feet basal area?

$Y = -5.0 + 0.4(40)$

$Y = 11$ percent

The following stocking equation represents the percent of the area stocked (Y) with ponderosa pine sawtimber (11.0 inches and larger).

$Y = 93.2 - 0.8X$

What is the percent of area stocked with ponderosa pine sawtimber at 65 square feet?

$Y = 93.2 - 0.8(65)$

$Y = 41$ percent

The examples illustrate use of stocking equations to determine stocking conditions by a species or a size class. Stocking equations can also be developed to express stocking conditions by trees exhibiting any of the other characteristics measured in this inventory.

Stand tables are also developed from the inventory. Stand tables describe the abundance of growing stock on an area by species and size class. They are also necessary for determining growth by a stand projection method.[4]

Point sampling, with any of the three BAFs, has proved satisfactory for constructing stand tables from the inventory data on the larger d.b.h. classes (7.0 inches d.b.h.). A strip cruise with narrow strips was used to develop stand tables in the smaller size classes, however, because of the clumped pattern of distribution. Stand tables may possibly be developed for all size classes from point-sampling techniques in forests with more uniform distribution in these smaller size classes.

STUDY AREA

The overstory inventory was field tested on a 450-acre study area on the Beaver Creek pilot watersheds.

Timber was last cut in a period from 1943-50, and half of the estimated merchantable sawtimber volume was removed. There has been no cutting since 1950.

Numbers of trees per acre, basal area per acre, and volume per acre were inventoried for each species on an area. These data are given for ponderosa pine, Gambel oak, and alligator juniper in table 3.

The soils are derived from basalt parent material. Soil management areas on the watershed are Siesta-Sponseller, a "high" timber producer,[5] and Stoneman, a "medium" producer.[5]

[4] *The stand projection method of growth determination used with this inventory was described by Hasel, A. A. A design for multipurpose forest surveys of large areas. 51 pp. (Unpublished manuscript on file in the U. S. Forest Service office, Washington, D. C.). Ffolliott (1965) shows how Hasel's method was applied in Arizona.*

[5] *Terms used to describe soil management area timber potentials, in Anderson, T. C., Jr., Williams, J. A., and Crezee, D. B. Soil management report for Beaver Creek watersheds of Coconino National Forest, Region 3. 66 pp., illus. 1960. (Mimeographed report on file at Region 3 office, U. S. Forest Serv., Albuquerque, N. Mex.)*

Table 3.--Number of trees, basal area, and volumes per acre for ponderosa pine, Gambel oak, and alligator juniper on study area

Size class[1]	Ponderosa pine			Gambel oak			Alligator juniper		
	Trees	Basal area	Volume[2]	Trees	Basal area	Volume[3]	Trees	Basal area	Volume[4]
	No.	Sq.ft.	Cu.ft.	No.	Sq.ft.	Cu.ft.	No.	Sq.ft.	Cu.ft.
Reproduction (1-4½ ft. height)	245	--	--	--	--	--	17.3	--	--
Saplings[5] (1-3 in. d.b.h.)	635	14.0	476	81.4	1.8	24.4	28.5	0.6	2.8
Poles[5] (4-10 in. d.b.h.)	166	31.0	488	39.0	7.5	89.3	7.1	.9	12.1
Sawtimber[5] (12 in. d.b.h. and larger)	18.2	32.0	794	4.6	5.0	84.0	2.6	11.9	94.8
Total	1,064.2	77.0	1,758	125.0	14.3	197.7	55.5	13.4	109.7

[1] Refers to diameter range; not to specific products.
[2] Basis: Myers (1963).
[3] Basis: Gevorkiantz and Olsen (1955).
[4] Basis: Extension and modification from Howell and Lexen (1939).
[5] Saplings measured by 1-inch classes; poles and sawtimber, by 2-inch classes.

PROPOSED MANAGEMENT SYSTEM

A management system is proposed for the study area to illustrate the use and the flexibility of the multiple BAF inventory. It was not designed to satisfy any particular management objective, only to model the inventory system.

Certain portions of the study area (fig. 1) are to be managed to produce four even-aged stand conditions in strips approximately 200 feet wide, shown schematically in figure 2. The area is to be managed on a 100-year rotation. The most practical of two courses of action will be followed in this conversion.

1. Immediate conversion system--The desired profile can be produced immediately if the spatial distribution of tree sizes permits 50 percent of each timbered strip to be stocked to 50 square feet basal area with the desired tree sizes (fig. 2a). Cleared strips will be planted with ponderosa pine. All alligator juniper and Gambel oak will be eliminated from the areas as they are cleared. All trees larger than called for on the timbered strips will be cut. Subsequent cuts to sustain the management pattern, the first of which will occur in 25 years on the large and medium saw-

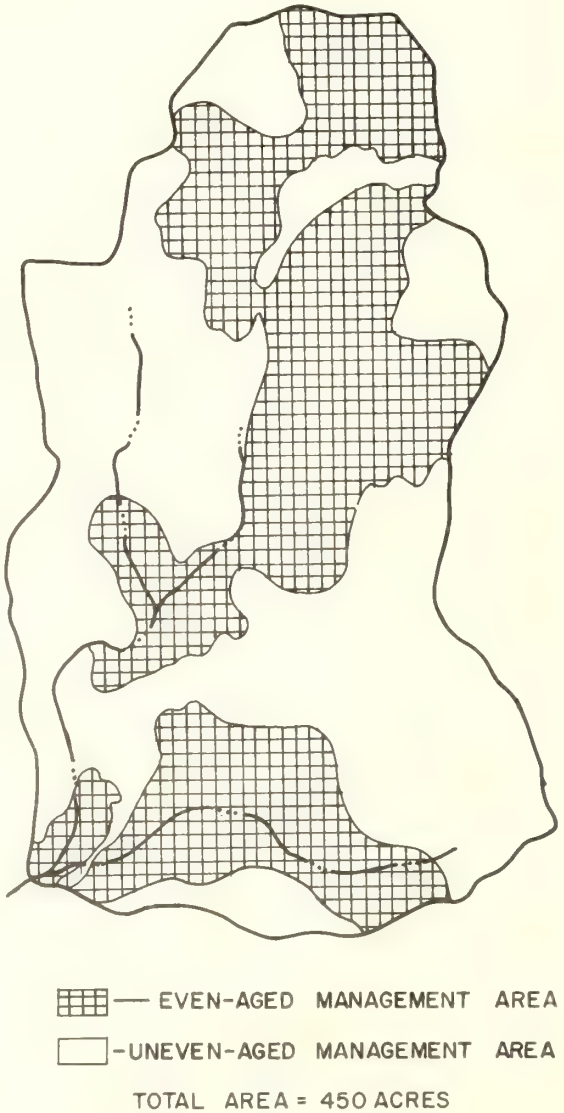

Figure 1.--Study area showing proposed management system.

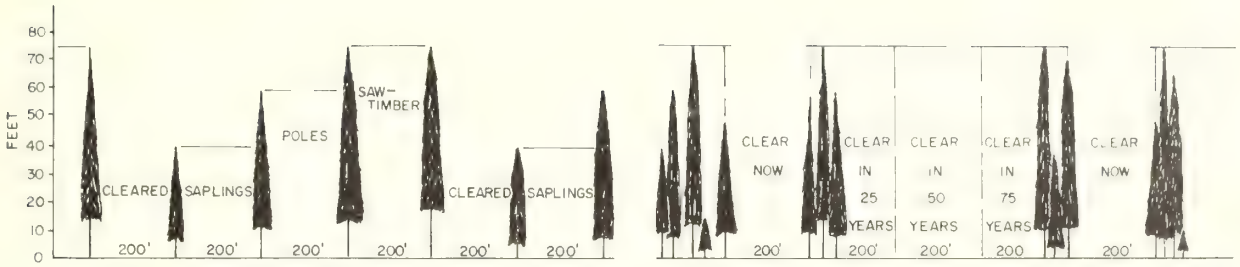

FIGURE 2

a. This schematic diagram illustrates the even-aged profile desired. Can this profile be produced immediately?

b. Perhaps existing timber stocking conditions require slow conversion by clearing successive strips every 25 years as illustrated here.

timber strip, will clear this area for planting. The area cleared now will then be the sapling size class.

2. Long-term conversion system.--If the timber overstory does not meet the criteria set forth for the immediate conversion system, the three timbered strips in that system (600 feet wide) will be left in their existing condition provided 50 percent of the area is covered with 75 square feet basal area in trees of all sizes. The conversion process will continue by clearing successive 200-foot strips at 25-year intervals (fig. 2b). Gambel oak and alligator juniper will be removed from the cleared areas but retained on uncleared areas as before.

The ponderosa pine on the remainder of the study area is to be managed by the group selection system along an uneven-aged management regulation system. The growing stock level for uneven-aged management must be compatible with a "q" [6] of 1.49, ascertained for the Fort Valley Experimental Forest, [7] at a practical level made possible by existing stocking. A graph of existing stocking and a proposed stocking level of 40 square feet per acre is shown in figure 3. The alligator juniper components of the overstory are to be eliminated, and the Gambel oak is to be retained for mast production.

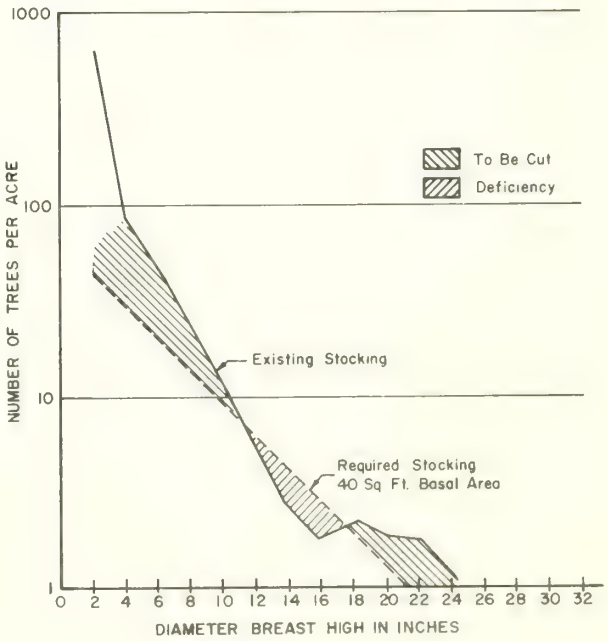

Figure 3.--Tree size distribution on uneven-aged management area.

[6] *"q" is defined as the average quotient between numbers of trees in consecutively smaller 2-inch d.b.h. classes (Myers 1962).*

[7] *Myers, C. A. Methods of cutting ponderosa pine in the southwest. 29 pp. (Study plan on Timber Management Project FS-RM-1203.10, submitted June 20, 1961; on file at Rocky Mountain Forest & Range Exp. Sta., U. S. Forest Serv., Ft. Collins, Colo.)*

Determining Management System Feasibility

The immediate problem is to determine whether the overstory is compatible with the proposed management system. The first specific question arises as to the steps to take to convert the designated area to even-aged conditions. The overstory is tested to see if immediate conversion to the strip pattern is feasible. Table 4 shows that less than 50 percent of the medium sawtimber and large pole strips meet the 50-square-foot basal area criteria. Only 40 percent and 30 percent, respectively, are stocked with those size classes now, so posttreatment stocking could be no better.

Table 4. --Proportion of area stocked with ponderosa pine of different size classes on even-aged portion of study area (based on stocking equation developed from inventory)

Size class on strip	Stocking level	Proportion of area	
		Not stocked	Stocked
	Sq. ft. basal area	Percent	
Medium and large sawtimber	50	60	40
Large poles and small sawtimber	50	70	30
Small poles and saplings	50	30	70

The stocking equation for ponderosa pine of all sizes combined shows that leaving the uncut strips in their existing condition will result in 80 percent of this area being stocked to the 75-square-foot criteria with trees of all sizes. Thus the long-range conversion system is feasible.

The remainder of the study area is to be managed by the group selection system. It must be determined whether this is feasible, and how long it will take to achieve a balanced distribution of size classes. The existing and required tree size distributions to achieve this balance at a 40-square-foot per acre basal area level are shown in figure 3. The trees represented by the area between the two lines when the existing distribution exceeds the required distribution would be cut. Slight deficiencies are present in the 14- and 16-inch diameter classes. Based on existing growth rates, a 30-year adjustment period will be required for the deficiency to be made up.

The existing size class distribution must be intermingled to manage this part of the study area by an uneven-aged system. The amount of intermingling can be determined by means of the stocking equations developed from the inventory.

The stocking equation shows that 13 percent of the watershed to be managed by an uneven-aged system is not stocked at a basal area level of 40 square feet per acre, the proposed management level. The intermingling of size classes on the area adequately stocked at 40 square feet per acre is illustrated in table 5. It should be noted that portions of this area are supporting three or more size classes. These are included in table 5 in order to show all the marking options open to produce the intermingling of size classes needed in uneven-aged management.

Table 5. --Intermingling of size classes on area stocked at basal area level of 40 square feet per acre

Size class	Sawtimber[1]	Poles[1]	Saplings[1]	Reproduction
	- - -	Percent of area		- - -
Sawtimber[1] (12 in. d.b.h. and larger)	14.5			
Poles[1] (4-10 in. d.b.h.)	23.5	14.0		
Saplings[1] (1-3 in. d.b.h.)	24.0	40.0	3.5	
Reproduction (1-4½ ft. height)	23.5	30.0	38.5	5.0

[1] Saplings measured by 1-inch classes; poles and sawtimber, by 2-inch classes.

Decision Summary

The findings are summarized as follows:

1. Conversion of this study area to even-aged strips will have to follow the long-term conversion system of clearing and planting successive strips every 25 years. The stocking by size classes in the uncut area is inadequate for immediate conversion.

2. The remainder of the study area can be managed according to the group selection form of uneven-aged management as prescribed at a level of 40 square feet per acre basal area.

MULTIPLE USE EVALUATION

For multiple use evaluation, the inventory must provide the information required so that specialists can determine the effects of a particular course of management on production in their specialties. Specific questions are posed about various uses and are answered for this study area by combining research results in these fields with inventory data. The inventory provides explicit data about trees and stands and their distribution for existing conditions, and provides a basis for estimating answers to the same questions after management is changed.

Watershed Management

Statement of Concern

While strip cuttings as proposed for the even-aged management portion of the study area have not been tried in the ponderosa pine type in the Southwest, this type of cutting has been an effective means of increasing streamflow in other forest types (Anderson and Gleason 1959, Hoover 1960). For demonstration purposes, it is assumed that strip cutting would be most effective where stands are dense and slopes 10 percent or greater.

Problem

Are the proposed strip cuttings located where the ponderosa pine is densest and on the steepest part of the study area?

Solution

Solve the stocking equation for ponderosa pine for a relatively high level of stocking to determine the proportion of the area stocked and overstocked at this level. The results for a 75-square-foot basal area level appear in table 6. Summarize the slope percents on each area to determine if they are steeper on the even-aged part than on the uneven-aged part (table 7).

Table 6.--Proportion of study area not stocked and stocked with ponderosa pine at basal area level of 75 square feet per acre

Proportion of study area	Total area	Even-aged portion	Uneven-aged portion
	Percent of area		
Not stocked	30	20	40
Stocked	70	80	60

Table 7.--Proportion of study area by slope percentages

Proportion of study area	Total area	Even-aged portion	Uneven-aged portion
	Percent of area		
Slope percentage:			
0	4	1	6
5	31	18	45
10	32	38	27
15	24	34	16
20	5	7	3
25	2	1	2
30	1	1	0
35	0	0	0
40	1	0	1

Conclusions

Eighty percent of the even-aged area is adequately stocked with ponderosa pine at a basal area level of 75 square feet per acre, while only 60 percent of the uneven-aged portion is thus stocked. Eighty-one percent of the even-aged portion is on slopes 10 percent or greater, while only 49 percent of the uneven-aged portion is this steep.

It is concluded that the even-aged portion of the study area is better suited for strip cutting to increase water yield than is the uneven-aged portion. Current streamflow records for this area show water yield to be 3.4 inches; the management change can be expected to increase this yield.

Timber Management

Statement of Concern

Reduction in timber stocking often immediately decreases timber growth per acre. Individual tree growth may increase, however, so that eventually timber growth per acre may increase.

Problem

Determine present ponderosa pine growth per acre, and show how this growth will be affected immediately following and 5 years after the management change.

Solution

Apply a stand projection method of growth determination to the stand tables and diameter growth data from the inventory. Required of the inventory are (1) pretreatment stand table and diameter growth for pretreatment growth determination; (2) posttreatment stand table to use with existing diameter growth to determine immediate growth response; and (3) a projection of expected diameter growth to use with the posttreatment stand table to estimate growth some years hence. Data for (1) and (2) are available from the inventory, while data for (3) will require research results on changes in diameter growth with time. The calculations are summarized in table 8.

Table 8.--Pretreatment and posttreatment growth rates[1] on study area

Size class[2]	Pre-treatment	Posttreatment	
		Immediate	5 years[3]
	Cubic feet per acre per year		
Poles[4] (4-10 in. d.b.h.)	22.9	10.0	12.3
Sawtimber[4] 12 in. d.b.h. and larger)	10.6	8.3	12.5
Total	33.5	18.3	24.8

[1] Difference between ingrowth and outgrowth in a diameter class. Basis: Myers (1963).
[2] Refers to diameter range; not to specific products.
[3] Growth based on preliminary analysis of data from already thinned areas on Beaver Creek.
[4] Measured by 2-inch classes.

Conclusions

1. Current growth amounts to about 33.5 cubic feet per acre per year.

2. Growth immediately after the management change is expected to be 55 percent of pretreatment growth, or 18.3 cubic feet per acre per year.

3. Growth 5 years after management change should amount to 74 percent of the current growth, or 24.8 cubic feet per acre per year.

4. Sawtimber growth after 5 years is estimated at 118 percent (18 percent increase) of current sawtimber growth.

Forest Management--Pathology

Statement of Concern

The importance of dwarfmistletoe in southwestern ponderosa pine is well known (Hawksworth 1961). The parasite both increases mortality and reduces host vigor.

Problem

What is the current incidence of dwarfmistletoe by size class on the study area? Can this be reduced immediately by the change in management?

Solution

Stand tables of all trees and of dwarfmistletoed trees, constructed from the inventory, show the current status of dwarfmistletoe incidence. Both management areas were test marked according to the prescription for the new management system, and similar stand tables for the new management were calculated. These data are summarized in table 9.

Conclusions

1. The current incidence of dwarfmistletoe is estimated at 8.3 percent of the total trees.

2. This incidence will remain essentially unchanged on the even-aged area.

3. Dwarfmistletoe can be eliminated from the remainder of the study area.

4. The incidence of dwarfmistletoe on the study area as a whole will be reduced about 50 percent.

Table 9. --Pretreatment and posttreatment incidence of dwarfmistletoe on study area

Size class[1]	Pretreatment		Posttreatment					
			Even-aged management		Uneven-aged management		Total	
	Total trees per acre	Dwarf-mistletoe infected	Total trees per acre	Dwarf-mistletoe infected	Total trees per acre	Dwarf-mistletoe infected	Total trees per acre	Dwarf-mistletoe infected
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Poles[2] (8-10 in. d.b.h.)	40.6	6.3	31.1	7.0	22.4	0	25.9	3.7
Sawtimber[2] (12 in. d.b.h. and larger)	19.7	12.5	15.6	10.9	14.6	0	15.0	5.1
Total	60.3	8.3	46.7	8.3	37.0	0	40.9	4.1

[1] Refers to diameter range; not to specific products.
[2] Measured by 2-inch classes.

Range Management

Statement of Concern

Livestock carrying capacity largely depends upon herbage production, which in turn is affected by the amount of tree cover. Herbage production decreases as basal area increases (Pase 1958).

Problem

Estimate existing herbage production, and show how the prescribed management may change production by applying the Pase (1958) equation as adjusted to Beaver Creek to appropriate basal area levels determined from the inventory.

Solution

The production equation adjusted for Beaver Creek is logarithm Y = 2.949 - 0.0096X, where Y is herbage production and X is basal area. This adjustment works well for the basal area levels included in the inventory. Cleared areas produce an average of 950 pounds per acre.[8] This production will apply to areas cleared to make the change to even-aged management.

To estimate current production, X equals existing basal area as determined from the inventory. Basal area under the new management equals the basal area left on each portion of the study area under the prescription for that portion. These basal areas are weighted according to the proportional area in each part of the study area, and summed to determine the new herbage production for the study area under the prospective management. The following shows the results of these calculations.

Conclusions

1. Present herbage production is about 160 pounds per acre per year.

2. Under the new management system, production is expected to increase 135 percent to about 380 pounds per acre per year.

Wildlife Management

Statement of Concern

Gambel oak is the mast producer of the study area. Maximum mast-producing oak on Beaver Creek have been determined to be 8 to 14 inches d.b.h. with more than 80 percent live crown.

Problem

What is the current abundance and distribution of optimum mast producers, and how

[8] *Based on unpublished data from a range production study on Beaver Creek.*

will this be changed by the proposed management system?

Solution

The present abundance of optimum mast-producing Gambel oak is determined by entering the stand table for trees with the above characteristics. Abundance following management change is determined by deducting trees to be cut according to the new management prescription. Distribution in each case is estimated by determining the proportion of sampled points occupied by trees of these characteristics at a 25-square-foot basal area level. This distribution is expressed as a percentage of total points. Also, the map (fig. 4) shows that Gambel oak is well distributed over the study area.

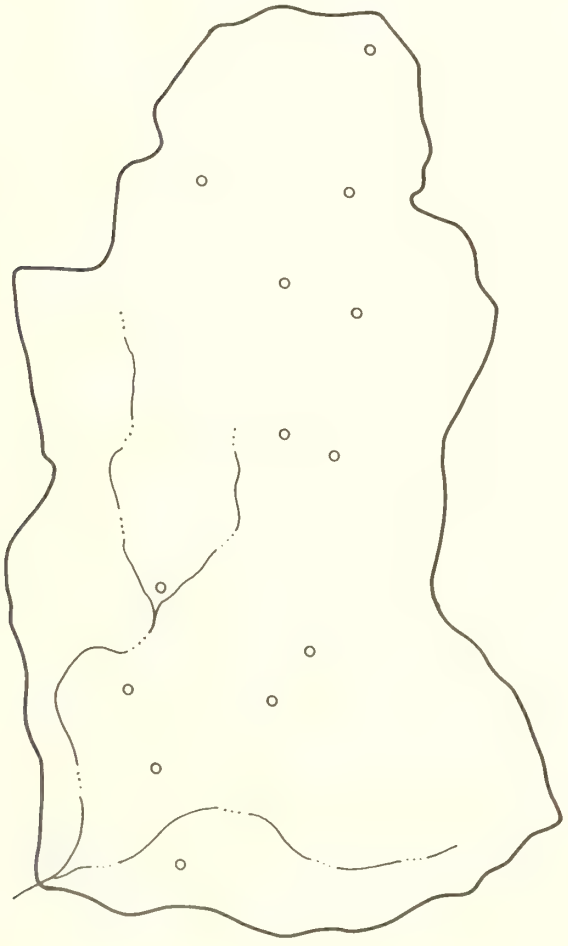

Figure 4.--Distribution of sample points stocked with Gambel oak to basal area of 25 square feet per acre.

Conclusions

1. Currently, there are 3.8 optimum mast-producing Gambel oak per acre well distributed over the study area. Seven percent of the area is occupied with Gambel oak at a basal area level of 25 square feet per acre or more.

2. After management redirection it is estimated there will be 3.4 trees per acre, and the Gambel oak should occupy 6.2 percent of the area to a basal area criteria of 25 square feet per acre or more.

Recreation Management

Statement of Concern

A uniform distribution of medium and large sawtimber trees creates an aesthetic setting for recreation activities. In the absence of definitive information with respect to optimum conditions, a criteria of 10 trees 18 inches and larger per acre has been arbitrarily set as optimum for casual recreation.

Problem

Estimate the proportion of the area currently supporting 10 trees 18 inches and larger per acre. How will this be changed by incorporating the management system?

Solution

From the inventory, a stocking equation was developed for trees 18 inches and larger d.b.h. This equation, $Y = 65.3 - 0.7X$, expresses the proportion of the study area currently supporting these trees at different basal area levels. The average diameter of trees in these size classes was determined from the stand table so the basal area level to meet the 10-tree criteria could be computed: 26 square feet per acre. This value of 26 for X in the stocking equation indicates that 47 percent of

the area is now supporting 10 trees 18 inches d.b.h. and larger.

A map of the spatial distribution of these trees, similar to figure 4 for Gambel oak, revealed that these trees are well distributed over the study area. In the area to be placed under even-aged management, 25 percent of the area is clearcut while the remainder is uncut except for high-risk trees, which do not change the stocking significantly. Stocking under the uneven-aged management system would not meet the specified recreation criteria. The calculations based on these facts predict that only 16 percent of the study area will meet the recreation specifications after management redirection.

Conclusions

1. Presently 47 percent of the study area meets the stocking requirements for casual recreation.

2. Under the proposed management only 16 percent of this area can be expected to meet this criteria.

COST OF MANAGEMENT CHANGE

The proposed change in management will cost money, but will also return money from the harvested products. Since the costs are borne by budgeted funds, they must be compared to costs of other projects to help decide on allocations of budgeted funds. Since immediate harvesting returns are divided between the Federal treasury and local counties in lieu of taxes, it is important to anticipate them.

Statement of Concern

Different forest products marketing arrangements can be expected to affect the costs and returns associated with the management proposal.

Problem

Estimate costs of clearing and thinning, and returns from the sale of pulpwood and sawtimber stumpage or from sawtimber stumpage alone.

Solution

1. Costs: Following the timber harvest, 50.6 acres are to be cleared. Typical clearing costs from the project area are about $50 per acre. This amounts to a total clearing cost of approximately $2,530. Costs following a sawtimber harvest in the absence of a pulpwood market are about $80 per acre. Clearing costs in this event would amount to $4,048.

The difference between existing and postmanagement stand tables for trees of subcommercial size developed from the inventory give the number of trees to be removed in the thinning operation (table 10).

Table 10.--Existing and postmanagement subcommercial stand table on study area

Diameter breast height (inches)	Trees per acre		
	Existing	Proposed management level	To be removed
	----- Number -----		
2	635	42.9	592.1
4	85.5	29.1	56.4
6	45.3	19.6	25.7
Total	765.8	91.6	674.2

Current thinning costs from the project area indicate total costs of $0.018 per tree. Thinning costs of $12.14 per acre are then anticipated, which will give a total thinning cost estimate of $3,005 for the 247.5 acres to be put under uneven-aged management. Since there is a question as to whether pulpwood-size trees can be sold, the additional cost of thinning pulpwood-size trees must also be calculated. Similar stand table comparisons suggest that 250 trees of pulpwood size per acre need to be removed. At a cost of about $0.06 each, these larger trees would increase clearing costs by $15.00 per acre or $3,713 for the study area.

2. Timber harvest returns: Estimated stand tables for the even-aged and uneven-aged

management areas after the change in management were subtracted from stand tables of existing merchantable-size trees. The difference was multiplied by the volume per tree (Myers 1963) adjusted to net volume from inventory data. These volumes were weighted and summed (table 11).

Table 11.--Merchantable timber volumes to be removed on study area

Management area	Sawtimber		Pulpwood	
	Average per acre	Total	Average per acre	Total
	Board feet		Cords	
Even-aged	1,430	288,800	1.81	365
Uneven-aged	1,780	450,500	1.31	324
Study area total		739,300		689

Exact stumpage prices need to be worked out for each logging chance. An estimate can be made, however, based on typical local prices and market restrictions. Sawtimber offerings of this volume per acre on similar terrain have averaged about $4 per thousand board feet. Pulpwood offerings have sold for about $1 per cord stumpage. A current pulpwood restriction, however, requires 2 cords per acre be harvested. The expected returns are calculated (1) on the basis of a sawtimber market only, and (2) on the basis of a sawtimber and pulpwood market in case the current pulpwood volume restriction is relaxed. In the first instance, the estimated stumpage return is $2,957 for the study area; if the pulpwood market is available the return would be $3,646.

Conclusions

1. The change in management is expected to cost $5,535 if pulpwood trees can be sold and $10,761 if they can not.

2. Timber harvests associated with the management change are expected to return $2,957 if only a sawtimber market is available, or $3,646 if both pulpwood and sawtimber markets are present.

A MULTIPLE USE SUMMARY OF THE PROPOSED MANAGEMENT SYSTEM

An analysis of inventory data by means of research findings shows the proposed management redirection is feasible under the existing conditions on the study area. It will be necessary to convert slowly on the even-aged management area, but the remaining areas can be converted immediately to the required level of uneven-aged management.

The effects of the proposed change in management on the items of concern discussed previously are summarized in table 12. This summary and the supporting calculations contain examples to illustrate the possibilities of the multiple BAF inventory system to provide data for answering multiple use questions. The questions cited and summarized constitute only a small fraction of possible questions.

This method of using research results to analyze and extrapolate inventory information provides quantitative physical data about the effects of a management decision on multiple use production. These data give decision makers one more basis to help decide whether to accept or reject a particular course of action on a specific tract of land.

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Table 12.--Effect of proposed management system on selected items of concern on study area

Items of special concern		Current status	Expected will change to--	Amount of change
WATERSHED MANAGEMENT:				
Streamflow	Inches per year	3.4	-	+
TIMBER MANAGEMENT:				
Timber growth	Cubic feet per acre per year	33.5	Immediately, 18.3; In 5 years, 24.8	-15.2 -8.7
FOREST MANAGEMENT--PATHOLOGY:				
Mistletoe incidence	Percent of total trees	8.3	4.1	-4.2
RANGE MANAGEMENT:				
Herbage production	Pounds per acre per year	160	380	+220
WILDLIFE MANAGEMENT:				
Mast-producing trees	Number per acre residual	3.8	3.4	-0.4
Percent of area stocked with 5 trees per acre, at a 25 square-foot basal area level		7.0	6.2	-0.8
RECREATION MANAGEMENT:				
Stocking of trees 18 inches d.b.h. and larger	Percent of area with 10 or more trees per acre	47	16	-31
COST OF MANAGEMENT CHANGE:				
Budget cost in dollars	With a sawtimber market	0	10,761	+10,761
	With an additional pulpwood market	0	5,530	+5,530
VALUE OF TIMBER HARVESTED:				
Immediate harvest returns in dollars	With a sawtimber market	0	2,957	+2,957
	With an additional pulpwood market	0	3,646	+3,646

Agriculture -- CSU, Ft. Collins

Ffolliott, Peter F., and Worley, David P.
1965. An inventory system for multiple use evaluations. U. S. Forest Serv. Res. Paper RM-17, 15 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Describes a multiple BAF (basal area factor) inventory system flexible enough to describe a forested tract so multiple use interpretations can be made from known relations of product yields to the inventory description of the resources on the tract. Basal area was selected as the inventory basis because it is (1) easily determined in the field; (2) easily converted to other expressions; and (3) many multiple use relations have already been developed with basal area as the independent variable. A multiple BAF system is a point-sampling system that uses several basal area factors to describe the stocking of trees. Its use is illustrated by hypothesizing forest management methods for a pilot watershed in Arizona.

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Potential Solar Beam Irradiation on Slopes:

Tables for 30° to 50° Latitude

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ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Fort Collins, Colorado — Raymond Price, Director
FOREST SERVICE — U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-18 March 1966

POTENTIAL SOLAR BEAM IRRADIATION ON SLOPES

Tables for 30° to 50° Latitude

by

Ernest C. Frank, Associate Hydrologist

and

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[2] Central headquarters maintained at Fort Collins in cooperation with Colorado State University.

POTENTIAL SOLAR BEAM IRRADIATION ON SLOPES

Tables for 30° to 50° Latitude

by

Ernest C. Frank and Richard Lee

Solar Energy Relations

Solar irradiation, the energy source to the hydrologic cycle, photosynthetic processes, and other natural phenomena, must be evaluated continually in diverse land management and research ventures. The establishment and protection of forests, and their yields of wood and water, are directly affected. Energy analyses for wild or agricultural lands invariably begin with data or assumptions relevant to the recurring input from the sun. In recent years this approach has emphasized the need for a quantitative description of such concepts as "southern exposure," "solar climate," or "topographic shading." Significant contributions have been those by Fons et al.(1960), Kaempfert and Morgen (1952), Loewe (1962), Milankovitch (1930), and Okanoue (1955).

The slope and orientation of terrain elements, especially important in forest hydrology, are important climatological factors as well. It is well known that the differential sunning of slopes alone can account for climatic extremes measurable in terms of equivalent latitudinal differences. The experienced forester recognizes the extent of such differences intuitively, and local management practices may reflect his artful tactics. Yet, scientific progress is facilitated to a greater extent by numerical qualification than by rules of thumb.

Solar beam irradiation is only one of several radiant energy components of importance in the radiation balance for natural areas, yet the differences between areas are often largely a function of this one parameter. Fairly uniform climatic changes with latitude are obviously recognizable and related directly to sun angle. This relationship has been confirmed from long-term measurements of the various components of radiation exchange. The typical relation is:

$$S = J + H + G - R - A \qquad (1)$$

where S is the net radiation balance, J the direct beam, H the diffuse sky, G the thermal atmospheric, R the reflected, and A the thermal terrestrial components. Data from two middle-latitude stations show that long-term averages of the additional terms H, G, R and A are largely self-canceling:

Station		(H + G) ÷ (R + A)
Davos, Switzerland	1959	0.961
Hamburg, Germany	1957-62	1.036

Just as ordinary climatological data are not adequate to describe day-to-day events meteorologically, direct-beam irradiation alone cannot describe a short-term radiation budget. Conversely, it is expected that mean values for this parameter will be as useful as mean temperature and precipitation values.

Radiation detectors and integrators are being used more widely with increasing acceptance of the usefulness of solar radiation values. This equipment is not used widely enough, however, to be a tool in the general classification of forest sites, empirical-theoretical radiation indexes have been evolved to meet such needs. Solar radiation values computed from the solar constant, an atmospheric attenuation constant (turbidity factor), and the geometry of a site with respect to the sun's rays, provide remarkably good long-term means. The kinds of parameters that change from day to day (clouds, smog, dust, and atmospheric moisture) make short-term forecasts much more uncertain.

A purely theoretical parameter--*potential solar beam irradiation*--is obtained by neglecting entirely the turbidity factor mentioned above (the influence of the atmosphere in depleting direct solar energy). The intensity on a surface is then proportional to the cosine of the angle of incidence. The incidence angle for a terrestrial surface depends in turn on the five independent variables: terrestrial latitude, hour angle (time of day), solar declination (time of year), surface inclination or steepness, and surface orientation (azimuth of slope).

Although potential solar beam irradiation usually differs appreciably from actual irradiation, it is an appropriate, if nonrigorous, basis for comparing the energy flux among the facets of a landscape. In addition, it may be considered as a permanent site factor, the only variation being a perfectly cyclical one and calculable. The tables that form the bulk of this report are the result of such calculations. They provide a means of (1) quantitatively distinguishing, in terms of potential insolation, between surfaces that differ as to latitude, slope inclination, and orientation, and (2) assessing the potential insolation received on selected dates by a specific surface, which facilitates seasonal comparisons. The tables give the potential solar beam irradiation in Langleys received during 1 solar day, and the sunrise-sunset times as hours before and after true solar noon for 24 dates during the year. Latitudes 30° and 50° North are covered by 2° increments. Slope inclinations from 0 to 100 percent by 10-percent increments, and slope orientation to 16 points of the compass are covered. For inclined surfaces the latitude and change in longitude needed to locate the equivalent slope, or horizontal surface parallel to the inclined surface, are tabulated. The total potential insolation received during 1 year, and a radiation index (R.I.) based on the annual values, are given for all surfaces.

Equations

The mathematical theory underlying computations of potential or extraterrestrial radiation was developed by Milankovitch (1930) in his classical "Mathematische Klimalehre." In somewhat altered symbolism, the instantaneous irradiation Is of a horizontal surface is given as:

$$Is = \frac{Io}{e^2} (\sin \theta \cdot \sin \delta + \cos \theta \cdot \cos \delta \cdot \cos wt) \quad (2)$$

where:

Io = solar constant
e = radius vector, ratio of the earth-sun distance at a particular time to its mean
θ = terrestrial latitude
δ = solar declination
w = angular velocity of the earth's rotation, 15 degrees per hour
t = time in hours from noon

The time of sunrise and sunset (t_1, negative and t_2, positive) is found by setting Is = 0 and solving for t, or

$$\cos wt = -\tan \theta \cdot \tan \delta \quad (3)$$

By integration of equation 2, the total radiant energy for the period of 1 solar day, Iq is found as

$$Iq = \frac{Io}{e^2} (2t \cdot \sin \theta \cdot \sin \delta + \frac{1}{w} \cdot \cos \theta \cdot \cos \delta \cdot 2 \cdot \sin wt) \quad (4)$$

To account for the inclination and orientation of sloping surfaces, Okanoue (1957) included the additional arguments, k = slope inclination, and h = slope azimuth. Slope inclination, azimuth, and latitude are used to compute θ' and α as follows:

$$\theta' = \sin^{-1} (\sin k \cdot \cos h \cdot \cos \theta + \cos k \cdot \sin \theta) \quad (5)$$

$$\alpha = \tan^{-1} \left[(\sin h \cdot \sin k) \div (\cos k \cdot \cos \theta - \cos h \cdot \sin k \cdot \sin \theta) \right] \quad (6)$$

These locate the equivalent slope (Lee 1962) which is the horizontal surface parallel to the inclined surface. The latitude of the equivalent slope is given by θ'. A negative θ' indicated an equivalent latitude south of the equator. The change in longitude (or hour angle) between the slope and its parallel horizontal surface is given by α. Okanoue's modification of equation 2 with reference to the idea of an equivalent slope becomes:

$$Is = \frac{Io}{e^2} (\sin \theta' \cdot \sin \delta + \cos \theta' \cdot \cos \delta \cdot \cos wt') \quad (7)$$

where $wt' = wt + \alpha$. Sunrise and sunset times for slopes are given by:

$$\cos wt' = -\tan \theta' \cdot \tan \delta \quad (8)$$

where it is understood that equation 3 continues as the limiting case (i.e., day-length on a horizontal surface is the maximum for a given latitude; the inclined plane may have a shorter, but never a longer, solar day than the horizon-

Table 1.--Input Data

Latitude ° '	Slope direction	Slope inclination Deg.	Min.	Percent	Solar declination Deg.	Min.	Dates, approx.		e^2	Io/e^2
30 00		0	00	0	+ 23	30	6/22		1.03297	1.93616
32 00	N	5	43	10	+ 21	58	6/1	7/12	1.03090	1.94005
34 00	NNE-NNW	11	19	20	+ 19	20	5/18	7/27	1.02728	1.94689
36 00	NE-NW	16	42	30	+ 15	35	5/3	8/10	1.02190	1.95714
38 00	ENE-WNW	21	48	40	+ 10	55	4/19	8/25	1.01528	1.96990
40 00	E-W	26	34	50	+ 5	38	4/4	9/9	1.00739	1.98553
42 00	ESE-WSW	30	58	60	0	00	3/21	9/23	0.99960	2.00080
44 00	SE-SW	35	00	70	- 5	38	3/7	10/8	0.99154	2.01706
46 00	SSE-SSW	38	40	80	- 10	55	2/20	10/22	0.98404	2.03243
48 00	S	41	59	90	- 15	35	2/7	11/5	0.97790	2.04520
50 00		45	00	100	- 19	20	1/24	11/19	0.97285	2.05582
					- 21	58	1/10	12/3	0.96938	2.06317
					- 23	30	12/22		0.96759	2.06699

Values for the Radius Vector e interpolated after List (1958).

tal facet at the same latitude). In certain instances double solar days may occur--both sunrise and sunset occur twice for the slope during one rotation period (24 hours). A common example is the north wall of a building in summer at a latitude (North) exceeding the declination in degrees.

Over the time period of a day or less, the total potential slope irradiation, Iq, is derived from the relation:

$$Iq = \frac{Io}{e^2}\left[(t_2 - t_1)\sin\theta' \cdot \sin\delta + \frac{12}{\pi} \cdot \cos\theta' \cdot \cos\delta \cdot (\sin wt_2' - \sin wt_1')\right] \quad (9)$$

where $\frac{12}{\pi}$ is $\frac{1}{w}$ in radians.

Explanation of Tables

A Fortran program for the IBM 1620 computer, incorporating equations 3, 4, 5, 6, 8, and 9, was used to obtain the tabulated values. Inputs for this program were the Io/e^2 values and the sine, cosine, and tangent (where necessary) of the latitudes, slopes, aspects, and declinations listed in table 1. The latitudes (30° to 50° North) include most of the conterminous United States, excluding only southern Texas and Louisiana, and most of Florida. While the potential insolation values listed apply equally to slope aspects symmetric with respect to a north-south axis (NNE-NNW, E-W, etc.) the sunrise and sunset times are for slopes with east-facing components only. Sunrise and sunset times on west-facing slopes are the reverse of those on east-facing slopes and, of course, their signs are reversed. In addition, the values of α for east-facing slopes are to the east, while for west-facing slopes the indicated longitude change is to the west.

Interpretation of the tables for latitudes in the southern hemisphere[3] is straightforward if minor differences in season lengths are ignored. Slope aspects are reversed; there is a 180° rotation of the north-south axis (N=S, NNE=SSW, etc.). The sign of the solar declination is reversed, and the date changes by approximately 6 months. Users of the tables can find corresponding dates in the southern hemisphere by inspection in table 1. There the corresponding date for the southern hemisphere is found by entering the table at the solar declination equivalent in value but opposite in sign to that for the date in the northern hemisphere. Sunrise and sunset times are given for southern hemisphere slopes with east-facing components, just as for the northern hemisphere.

True solar time was used exclusively in the computations. True solar time is reckoned as the number of hours before (-) or after (+) solar noon--the moment the geometric center of the sun crosses the meridian (longitude) of the observer. Likewise, for our purposes, the sun rises and sets when its geometric center

southern third of South America, south[illegible] of South Africa.

crosses the horizon. Sample calculations for converting the true solar times of sunrise and sunset used in the tables to local standard times are given in the appendix.

The 13 solar declinations were chosen according to the approximate relation:

$$\delta = 23.5 \sin N \qquad (10)$$

where N is the number of days to the nearest equinox. Each quarter year is assumed to contain 90 days, and solutions to equation 10 can be arranged to yield declinations representative of approximately equal numbers of days. Except for the solstice dates (June 22 and December 22) each declination is represented by two dates as shown in table 1.

The radius vector e varies seasonally, and is used as a correction for the solar constant to account for the varying earth-sun distance. Neglect of this correction introduces an error equal to the range of variation of solar energy outside the atmosphere, or about 6.7 percent. The fact that e is not a simple function of declination δ presents a minor complication. The procedure used was to take an arithmetic average of e for the 2 days represented by a single declination. The error involved in this approximation is less than one percent.

Solutions to equations 5 and 6, representing the latitudes and changes in longitude of parallel horizontal surfaces, are given in the tables for each slope-aspect combination. These will be interesting in a geographic sense, because they indicate to some degree the relative change in solar climate to be expected.

Annual radiation totals based on a 365-day year, not 365.24 days, expressed in thousands Langleys (kg-cal/cm^2) are derived by weighting each of the daily totals according to the number of days for which each is representative. The R.I.'s for each slope are the ratios of annual radiation totals to the annual maximum potential solar beam irradiation. Since the mean day length at any latitude is 12 hours, the maximum potential insolation for the year is the solar constant times the duration of sunshine for the year:

$$2.0 \cdot 365 \cdot 12 \cdot 60 = 525{,}600 \text{ Langleys.}$$

The indexes are directly comparable for all surfaces regardless of latitude.

The R.I.'s, purely theoretical quantities, have application possibilities in forestry, ecology, and climatology as relative measures of the solar climate for sites. Land classification systems can well afford this elementary additional measure of the topoclimate. The indexes can also be used for more refined empirical-theoretical evaluations, as when experience permits the assignment of a mean turbidity factor to a locality for a day, season or year.

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Appendix: Sample Calculations

Local standard time is based on a *mean solar time* for 15° longitudinal zones; Eastern Standard Time, for example, is 75th Meridian time. The mean solar time for a locality is earlier (or later) then local standard time by 4 minutes per degree of longitude measured east (or west) to the time zone meridian. Thus, mean solar time at Pittsburgh (80° West) is 20 minutes earlier than Eastern Standard Time; at New York City (74° West) it is 4 minutes later.

True solar time at a site differs from mean solar time through the approximate range, -14 minutes to +16 minutes as shown in table 2. This difference is commonly referred to as the Equation of Time. From table 2, true solar noon on May 3rd occurs 3.1 minutes before mean solar noon. To complete the example for Pittsburgh, the sun actually crosses the 80th meridian on May 3rd at 20.0 - 3.1 = 16.9 minutes after noon, or at about 12:17 p.m. Eastern Standard Time. And on February 7th, true solar noon at New York City occurs at -4 + 14.2 = 10.2 minutes after noon, or at 12:10 EST.

Table 2.--Equation of Time, After List (1958) (Subtract Equation of Time from true solar time to obtain mean solar time).

Date	Equation of Time	
	Min.	Hrs.
Jan 10	- 7.2	-0.12
24	-12.0	-0.20
Feb 7	-14.2	-0.24
20	-13.9	-0.23
Mar 7	-11.3	-0.19
21	- 7.5	-0.13
Apr 4	- 3.3	-0.05
19	+ 0.5	+0.01
May 3	+ 3.1	+0.05
18	+ 3.7	+0.06
June 1	+ 2.4	+0.04
22	- 1.6	-0.03
July 12	- 5.4	-0.09
27	- 6.4	-0.11
Aug 10	- 5.4	-0.09
25	- 2.3	-0.04
Sept [illegible]	+ 2.4	+0.04
23	+ 7.3	+0.12
Oct 8	+12.1	+0.20
22	+15.3	+0.26
Nov 5	+16.4	+0.27
19	+14.7	+0.25
Dec 3	+10.5	+0.17
22	+ 1.8	+0.03

In this way, any of the sunrise and sunset times in the tables can be adjusted to local standard time. For example:

(a) The solar day for a 40 percent east-facing slope at Grand Canyon, Arizona (36° North, 112° West), on December 22nd begins at -4.77 hours and ends at +3.15 hours. The corresponding Mountain Standard (105° Meridian) Times are found as follows:

True solar times	-4.77 hrs. and	+3.15 hrs.
Mean solar times are earlier by 0.03 hr. (table 2)	-4.80 hrs. and	+3.12 hrs.
Mountain Standard Times are later by 112° - 105° = 7°, or 7/15 hr. (0.47)	-4.33 hrs. and	+3.59 hrs.
Mountain Standard Time	7:40 a.m. and	3:35 p.m.

(b) For a 40 percent west-facing slope at Grand Canyon on December 22nd, the solar day would begin at -3.15 hours and end at +4.77 hours. The corresponding Mountain Standard Times are found as follows:

True solar times	-3.15 hrs. and	+4.77 hrs.
Mean solar times are earlier by 0.03 hr. (table 2)	-3.18 hrs. and	+4.74 hrs.
Mountain Standard Times are later by 112° - 105° = 7°, or 7/15 hr. (0.47)	-2.71 hrs. and	+5.21 hrs.
Mountain Standard Time	9:17 a.m. and	5:13 p.m.

(c) Sunrise and sunset March 21st on a horizontal surface at Fort Collins, Colorado (40° North, 105° West) occur at -6.00 and +6.00 hours true solar time. The longitude coincides with the standard time zone meridian, so that the only correction required is the Equation of Time.

True solar times	-6.00 hrs. and	+6.00 hrs.
Mean solar times are later by 0.13 hr. (table 2)	-5.87 hrs. and	+6.13 hrs.
Mountain Standard Time	6:08 a.m. and	6:08 p.m.

List of symbols

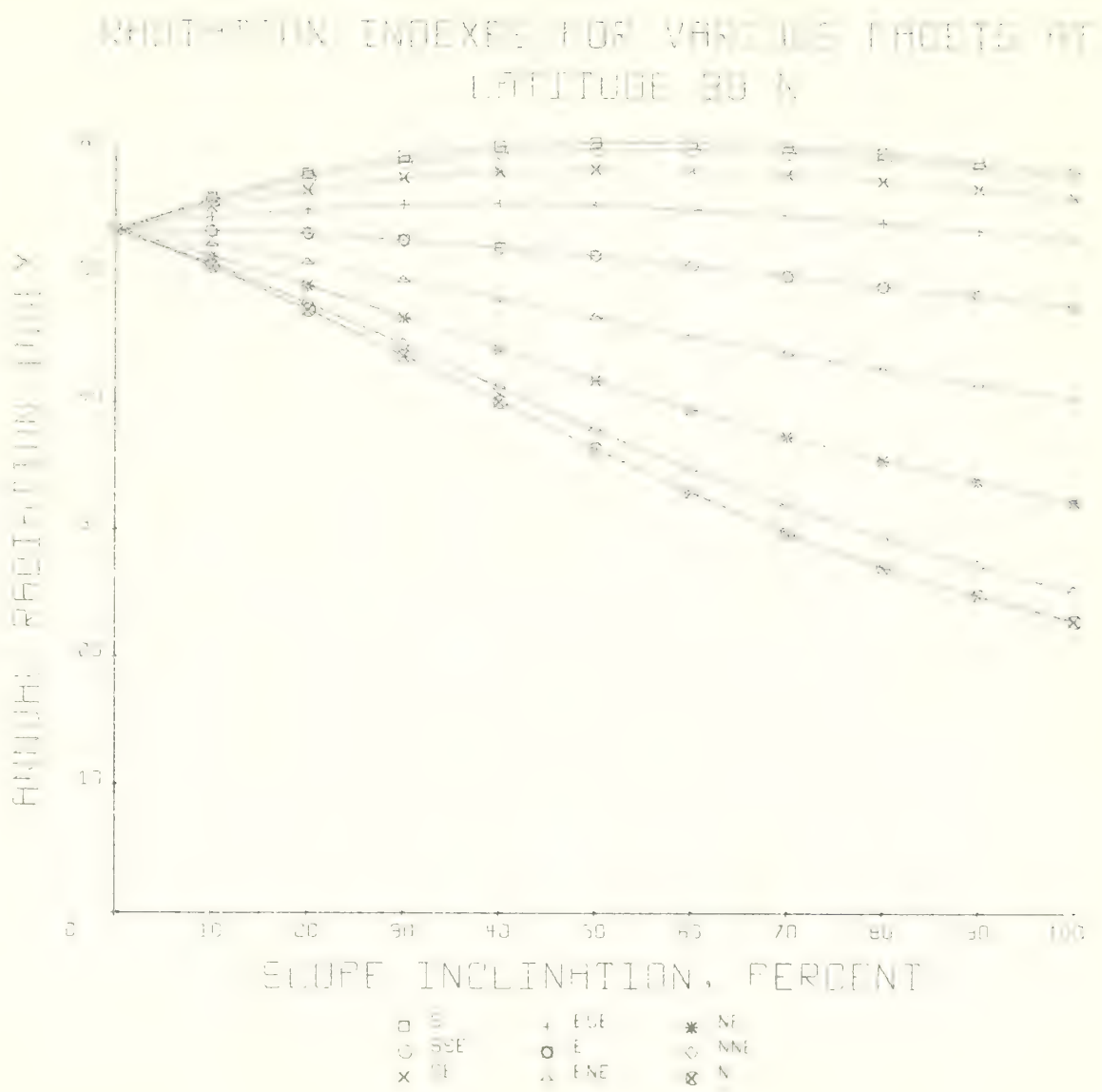
THETA	Equivalent latitude in degrees--the terrestrial latitude where a horizontal surface parallel or "equivalent" to the inclined surface is found.
ALPHA	Change in longitude in degrees--the difference in longitude between the location of the inclined surface and its "equivalent" horizontal surface. Alpha is to the east for aspects with an east component, and to the west for aspects with a west component.
SR SS	The elapsed time in hours from true solar noon at which the geometric center of the solar disc crosses the horizon.
LY	Total potential insolation in Langleys (gram calories/cm^2) received by the surface during the solar day on the given date.
YEAR	Total annual potential insolation in thousands of Langleys (kilogram calories/cm^2) received by the surface.
R.I.	Radiation index--the ratio of the total annual potential insolation to the maximum potential insolation at the site.

ORIENTATION SURFACE

LATITUDE 30 N

			SA	SS	LY
			-6.97	6.97	1008.1
JAN	1	JUL 12	-6.70	6.70	969.9
MAY	28	JUL 27	-6.78	6.78	976.3
MAY	1	AUG 10	-6.62	6.62	947.3
APR	18	AUG 25	-6.43	6.43	906.9
APR	4	SEP 9	-6.22	6.22	856.7
MAR	21	SEP 23	-6.00	6.00	794.2
MAR	7	OCT 6	-5.78	5.78	726.8
FEB	20	OCT 22	-5.57	5.57	658.5
FEB	7	NOV 5	-5.38	5.38	594.4
JAN	23	NOV 19	-5.22	5.22	540.9
JAN	10	DEC 3	-5.10	5.10	502.4
DEC	22		-5.03	5.03	479.6

YEAR	R.I.
282.118	.5368



LATITUDE 30 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 35.7		ALPHA 0.0	THETA 41.3		ALPHA 0.0	THETA 46.7		ALPHA 0.0	THETA 51.8		ALPHA 0.0	THETA 56.6		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.97	1016.6	-6.97	6.97	1018.0	-6.97	6.97	1010.2	-6.97	6.97	994.6	-6.97	6.97	972.9
JUN 1 JUL 12	-6.90	6.90	1001.8	-6.90	6.90	999.0	-6.90	6.90	987.2	-6.90	6.90	968.0	-6.90	6.90	943.2
MAY 18 JUL 27	-6.78	6.78	975.6	-6.78	6.78	965.5	-6.78	6.78	947.1	-6.78	6.78	922.0	-6.78	6.78	891.9
MAY 3 AUG 10	-6.62	6.62	936.2	-6.62	6.62	916.2	-6.62	6.62	888.8	-6.62	6.62	855.5	-6.62	6.62	818.3
APR 19 AUG 25	-6.43	6.43	883.3	-6.43	6.43	851.7	-6.43	6.43	813.6	-6.43	6.43	770.9	-6.43	6.43	725.5
APR 4 SEP 9	-6.22	6.22	819.0	-6.22	6.22	775.1	-6.22	6.22	725.9	-6.22	6.22	673.4	-6.22	6.22	619.5
MAR 21 SEP 23	-6.00	6.00	744.6	-6.00	6.00	688.8	-6.00	6.00	629.0	-6.00	6.00	567.1	-6.00	6.00	505.3
MAR 7 OCT 8	-5.73	5.73	665.7	-5.67	5.67	599.5	-5.60	5.60	530.7	-5.52	5.52	461.4	-5.43	5.43	393.6
FEB 20 OCT 22	-5.47	5.47	588.1	-5.35	5.35	514.0	-5.21	5.21	438.8	-5.05	5.05	365.0	-4.87	4.87	294.4
FEB 7 NOV 5	-5.23	5.23	517.0	-5.05	5.05	437.5	-4.85	4.85	358.7	-4.62	4.62	286.0	-4.33	4.33	212.5
JAN 23 NOV 19	-5.03	5.03	459.0	-4.80	4.80	376.3	-4.54	4.54	296.0	-4.23	4.23	220.4	-3.86	3.86	151.9
JAN 10 DEC 3	-4.88	4.88	417.8	-4.62	4.62	333.7	-4.31	4.31	253.1	-3.94	3.94	178.6	-3.49	3.49	112.9
DEC 22	-4.79	4.79	393.8	-4.50	4.50	309.1	-4.17	4.17	228.6	-3.76	3.76	155.3	-3.25	3.25	91.7
	YEAR 266.526		R.I. .5071	YEAR 248.949		R.I. .4736	YEAR 230.131		R.I. .4378	YEAR 210.819		R.I. .4011	YEAR 191.753		R.I. .3648

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 61.0		ALPHA 0.0	THETA 75.0		ALPHA 0.0	THETA 65.0		ALPHA 0.0	THETA 68.7		ALPHA 0.0	THETA 72.0		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.97	946.9	-6.97	6.97	918.1	-6.97	6.97	888.0	-6.97	6.97	857.7	-6.97	6.97	827.6
JUN 1 JUL 12	-6.90	6.90	914.4	-6.90	6.90	883.4	-6.90	6.90	851.3	-6.90	6.90	819.3	-6.90	6.90	787.8
MAY 18 JUL 27	-6.78	6.78	858.6	-6.78	6.78	823.7	-6.78	6.78	788.4	-6.78	6.78	753.7	-6.78	6.78	719.9
MAY 3 AUG 10	-6.62	6.62	779.0	-6.62	6.62	738.8	-6.62	6.62	699.2	-6.62	6.62	660.8	-6.62	6.62	624.0
APR 19 AUG 25	-6.43	6.43	679.1	-6.43	6.43	633.1	-6.43	6.43	588.5	-6.43	6.43	546.1	-6.43	6.43	505.9
APR 4 SEP 9	-6.22	6.22	565.9	-6.22	6.22	513.9	-6.22	6.22	464.4	-6.22	6.22	417.9	-6.22	6.22	374.4
MAR 21 SEP 23	-6.00	6.00	445.1	-6.00	6.00	387.6	-6.00	6.00	333.6	-6.00	6.00	283.7	-6.00	6.00	237.3
MAR 7 OCT 8	-5.32	5.32	329.0	-5.19	5.19	268.4	-5.02	5.02	212.7	-4.82	4.82	162.2	-4.56	4.56	116.7
FEB 20 OCT 22	-4.64	4.64	228.7	-4.37	4.37	169.0	-4.03	4.03	116.1	-3.58	3.58	70.8	-2.93	2.93	33.6
FEB 7 NOV 5	-3.99	3.99	148.9	-3.55	3.55	93.6	-2.96	2.96	48.1	-2.06	2.06	14.3	0.00	0.00	0.0
JAN 23 NOV 19	-3.39	3.39	92.6	-2.75	2.75	44.2	-1.74	1.74	9.9	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	-2.89	2.89	58.2	-2.01	2.01	17.4	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-2.56	2.56	40.5	-1.41	1.41	6.1	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 173.617		R.I. .3303	YEAR 157.014		R.I. .2987	YEAR 142.899		R.I. .2719	YEAR 131.083		R.I. .2494	YEAR 120.797		R.I. .2298

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 30 N
ASPECT S -

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	24.3	0.0	18.7	0.0	13.3	0.0	8.2	0.0	3.4	0.0

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.75	6.75	984.8	-6.56	6.56	957.4	-6.39	6.39	924.1	-6.24	6.24	886.4	-6.10	6.10	846.0
JUN 1 JUL 12	-6.70	6.70	979.1	-6.52	6.52	955.9	-6.36	6.36	926.4	-6.22	6.22	892.2	-6.09	6.09	854.7
MAY 18 JUL 27	-6.61	6.61	968.0	-6.45	6.45	952.0	-6.32	6.32	929.1	-6.19	6.19	900.7	-6.08	6.08	868.5
MAY 3 AUG 10	-6.48	6.48	949.6	-6.36	6.36	943.5	-6.25	6.25	929.8	-6.15	6.15	910.0	-6.06	6.06	885.3
APR 19 AUG 25	-6.33	6.33	921.7	-6.25	6.25	927.7	-6.17	6.17	925.5	-6.11	6.11	916.2	-6.04	6.04	901.1
APR 4 SEP 9	-6.17	6.17	884.0	-6.13	6.13	903.3	-6.09	6.09	913.8	-6.05	6.05	916.5	-6.02	6.02	912.4
MAR 21 SEP 23	-6.00	6.00	836.0	-6.00	6.00	868.8	-6.00	6.00	892.5	-6.00	6.00	907.7	-6.00	6.00	915.5
MAR 7 OCT 8	-5.78	5.78	780.8	-5.78	5.78	826.2	-5.78	5.78	862.4	-5.78	5.78	889.6	-5.78	5.78	908.7
FEB 20 OCT 22	-5.57	5.57	722.7	-5.57	5.57	778.7	-5.57	5.57	825.4	-5.57	5.57	863.0	-5.57	5.57	892.0
FEB 7 NOV 5	-5.38	5.38	666.4	-5.38	5.38	730.6	-5.38	5.38	785.7	-5.38	5.38	831.5	-5.38	5.38	868.4
JAN 23 NOV 19	-5.22	5.22	618.3	-5.22	5.22	688.3	-5.22	5.22	749.3	-5.22	5.22	801.0	-5.22	5.22	843.7
JAN 10 DEC 3	-5.10	5.10	583.1	-5.10	5.10	656.6	-5.10	5.10	721.3	-5.10	5.10	776.8	-5.10	5.10	823.1
DEC 22	-5.03	5.03	562.0	-5.03	5.03	637.3	-5.03	5.03	704.0	-5.03	5.03	761.5	-5.03	5.03	809.7

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
295.124	.5615	305.206	.5807	312.305	.5942	316.616	.6024	318.484	.6059

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	-1.0	0.0	-5.0	0.0	-8.7	0.0	-12.0	0.0	-15.0	0.0

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-5.97	5.97	804.4	-5.85	5.85	762.9	-5.75	5.75	722.6	-5.65	5.65	684.1	-5.55	5.55	647.6
JUN 1 JUL 12	-5.97	5.97	815.8	-5.87	5.87	776.5	-5.77	5.77	738.1	-5.67	5.67	701.2	-5.59	5.59	666.0
MAY 18 JUL 27	-5.98	5.98	834.1	-5.88	5.88	798.8	-5.80	5.80	763.7	-5.72	5.72	729.6	-5.64	5.64	696.9
MAY 3 AUG 10	-5.98	5.98	857.6	-5.91	5.91	828.1	-5.84	5.84	798.0	-5.77	5.77	768.2	-5.71	5.71	739.0
APR 19 AUG 25	-5.99	5.99	881.9	-5.94	5.94	859.9	-5.89	5.89	836.4	-5.84	5.84	812.2	-5.80	5.80	788.0
APR 4 SEP 9	-5.99	5.99	903.1	-5.97	5.97	890.0	-5.94	5.94	874.2	-5.92	5.92	856.9	-5.90	5.90	838.7
MAR 21 SEP 23	-6.00	6.00	917.0	-6.00	6.00	913.6	-6.00	6.00	906.6	-6.00	6.00	897.1	-6.00	6.00	885.8
MAR 7 OCT 8	-5.78	5.78	920.8	-5.78	5.78	927.1	-5.78	5.78	928.8	-5.78	5.78	927.1	-5.78	5.78	922.9
FEB 20 OCT 22	-5.57	5.57	913.3	-5.57	5.57	928.0	-5.57	5.57	937.5	-5.57	5.57	942.7	-5.57	5.57	944.7
FEB 7 NOV 5	-5.38	5.38	897.1	-5.38	5.38	918.7	-5.38	5.38	934.5	-5.38	5.38	945.5	-5.38	5.38	952.7
JAN 23 NOV 19	-5.22	5.22	877.8	-5.22	5.22	904.6	-5.22	5.22	925.1	-5.22	5.22	940.3	-5.22	5.22	951.4
JAN 10 DEC 3	-5.10	5.10	860.6	-5.10	5.10	890.9	-5.10	5.10	914.4	-5.10	5.10	932.4	-5.10	5.10	946.2
DEC 22	-5.03	5.03	849.3	-5.03	5.03	881.2	-5.03	5.03	906.4	-5.03	5.03	926.0	-5.03	5.03	941.2

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
318.341	.6057	316.635	.6024	313.785	.5970	310.152	.5901	305.988	.5822

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	35.3	2.7	40.3	5.7	45.1	9.0	49.6	12.7	53.6	16.8

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.97	1015.3	-6.97	6.97	1015.5	-6.97	6.97	1006.6	-6.97	6.97	989.9	-6.97	6.97	967.3
JUN 1 JUL 12	-6.90	6.90	1000.9	-6.90	6.90	997.2	-6.90	6.90	984.6	-6.90	6.90	964.7	-6.90	6.90	939.1
MAY 18 JUL 27	-6.78	6.78	975.3	-6.78	6.78	964.9	-6.78	6.78	946.2	-6.78	6.78	920.8	-6.78	6.78	890.5
MAY 3 AUG 10	-6.62	6.58	936.7	-6.62	6.54	917.2	-6.62	6.49	890.3	-6.62	6.43	857.7	-6.62	6.36	821.0
APR 19 AUG 25	-6.43	6.34	884.8	-6.43	6.25	854.9	-6.43	6.15	818.6	-6.43	6.03	777.9	-6.43	5.89	734.5
APR 4 SEP 9	-6.22	6.09	821.7	-6.22	5.94	780.8	-6.22	5.78	735.1	-6.22	5.60	686.4	-6.22	5.39	636.7
MAR 21 SEP 23	-6.00	5.82	748.5	-6.00	5.62	697.4	-6.00	5.40	642.9	-6.00	5.16	587.3	-6.00	4.88	532.5
MAR 7 OCT 8	-5.78	5.56	670.7	-5.78	5.30	610.6	-5.78	5.02	549.1	-5.78	4.71	488.1	-5.78	4.37	429.8
FEB 20 OCT 22	-5.57	5.30	593.9	-5.57	4.99	526.9	-5.57	4.66	460.1	-5.57	4.28	395.8	-5.57	3.87	335.7
FEB 7 NOV 5	-5.38	5.06	523.4	-5.38	4.71	451.6	-5.38	4.32	381.6	-5.38	3.88	315.6	-5.38	3.40	255.5
JAN 23 NOV 19	-5.22	4.86	465.7	-5.22	4.47	390.9	-5.22	4.03	319.3	-5.22	3.53	253.0	-5.22	2.99	194.0
JAN 10 DEC 3	-5.07	4.72	424.7	-5.04	4.29	348.4	-5.00	3.81	276.3	-4.96	3.27	210.6	-4.91	2.67	153.0
DEC 22	-4.99	4.63	400.7	-4.93	4.18	323.8	-4.87	3.67	251.7	-4.80	3.11	186.6	-4.71	2.47	130.3

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
267.736	.5094	251.591	.4787	234.400	.4460	216.868	.4126	199.670	.3799

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	57.2	21.3	60.3	26.3	62.9	31.7	65.1	37.4	66.8	43.4

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.97	940.4	-6.97	6.97	910.9	-6.97	6.97	880.2	-6.97	6.97	849.3	-6.97	6.97	818.7
JUN 1 JUL 12	-6.90	6.90	909.8	-6.90	6.90	878.2	-6.90	6.90	845.6	-6.90	6.90	813.2	-6.90	6.90	781.4
MAY 18 JUL 27	-6.78	6.78	857.0	-6.78	6.78	821.9	-6.78	6.78	786.4	-6.78	6.77	751.5	-6.78	6.77	717.6
MAY 3 AUG 10	-6.62	6.29	782.3	-6.62	6.20	742.8	-6.62	6.09	703.8	-6.62	5.97	666.2	-6.62	5.81	630.2
APR 19 AUG 25	-6.43	5.74	690.3	-6.43	5.56	646.5	-6.43	5.37	604.5	-6.43	5.14	564.9	-6.43	4.89	527.8
APR 4 SEP 9	-6.22	5.17	587.7	-6.22	4.91	540.7	-6.22	4.63	496.6	-6.22	4.32	456.2	-6.22	3.99	419.3
MAR 21 SEP 23	-6.00	4.58	480.0	-6.00	4.25	431.1	-6.00	3.89	386.5	-6.00	3.51	346.7	-6.00	3.10	311.5
MAR 7 OCT 8	-5.78	3.99	375.5	-5.78	3.58	326.3	-5.78	3.15	282.9	-5.78	2.69	245.2	-5.78	2.22	213.0
FEB 20 OCT 22	-5.57	3.42	281.4	-5.57	2.93	233.6	-5.57	2.41	192.7	-5.57	1.87	158.5	-5.57	1.32	130.4
FEB 7 NOV 5	-5.38	2.87	202.6	-5.38	2.30	157.5	-5.38	1.69	120.2	-5.38	1.05	90.5	-5.38	.39	67.4
JAN 23 NOV 19	-5.22	2.38	143.3	-5.22	1.72	101.4	-5.22	1.00	68.3	-5.22	.24	43.4	-5.22	-.57	25.5
JAN 10 DEC 3	-4.84	2.00	104.7	-4.75	1.25	66.1	-4.64	.42	37.0	-4.48	-.51	16.8	-4.20	-1.59	4.5
DEC 22	-4.59	1.75	83.9	-4.44	.94	47.8	-4.23	.01	21.8	-3.87	-1.12	5.6	0.00	0.00	0.0

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
183.370	.3489	168.339	.3203	154.847	.2946	143.001	.2721	132.740	.2525

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 30 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	24.7		2.4	19.5		4.6	14.4		6.5	9.6		8.3	5.1		9.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.93	6.61	986.5	-6.89	6.28	961.7	-6.86	5.99	931.6	-6.83	5.73	897.5	-6.81	5.49	860.9
JUN 1 JUL 12	-6.87	6.55	980.5	-6.85	6.24	959.6	-6.83	5.96	933.1	-6.81	5.71	902.3	-6.80	5.48	868.6
MAY 18 JUL 27	-6.78	6.46	968.9	-6.78	6.17	954.7	-6.78	5.91	934.4	-6.78	5.67	909.2	-6.78	5.46	880.6
MAY 3 AUG 10	-6.62	6.33	949.7	-6.62	6.07	944.8	-6.62	5.84	933.2	-6.62	5.63	916.0	-6.62	5.44	894.5
APR 19 AUG 25	-6.43	6.18	920.8	-6.43	5.96	927.1	-6.43	5.75	926.0	-6.43	5.57	918.5	-6.43	5.41	905.8
APR 4 SEP 9	-6.22	6.01	882.1	-6.22	5.83	900.4	-6.22	5.66	910.8	-6.22	5.51	914.0	-6.22	5.37	911.1
MAR 21 SEP 23	-6.00	5.84	832.8	-6.00	5.70	863.3	-6.00	5.57	885.3	-6.00	5.45	899.5	-6.00	5.34	906.6
MAR 7 OCT 8	-5.78	5.67	776.6	-5.78	5.56	818.3	-5.78	5.47	851.2	-5.78	5.38	875.7	-5.78	5.31	892.6
FEB 20 OCT 22	-5.57	5.50	717.7	-5.57	5.43	768.8	-5.57	5.38	811.2	-5.57	5.32	844.9	-5.57	5.27	870.3
FEB 7 NOV 5	-5.38	5.35	660.7	-5.38	5.32	719.4	-5.38	5.29	769.3	-5.38	5.27	810.4	-5.38	5.24	843.0
JAN 23 NOV 19	-5.22	5.22	612.2	-5.22	5.22	676.3	-5.22	5.22	731.7	-5.22	5.22	778.3	-5.22	5.22	816.3
JAN 10 DEC 3	-5.10	5.10	576.8	-5.10	5.10	644.1	-5.10	5.10	703.1	-5.10	5.10	753.2	-5.10	5.10	794.6
DEC 22	-5.03	5.03	555.5	-5.03	5.03	624.6	-5.03	5.03	685.4	-5.03	5.03	737.4	-5.03	5.03	780.7
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	294.148		.5596	303.485		.5774	310.055		.5899	314.028		.5975	315.721		.6007

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	1.0		11.4	-2.8		12.7	-6.3		13.9	-9.4		15.0	-12.3		16.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.79	5.27	823.2	-6.76	5.07	785.6	-6.74	4.89	749.0	-6.73	4.72	714.1	-6.71	4.57	680.9
JUN 1 JUL 12	-6.78	5.27	833.5	-6.77	5.08	798.1	-6.76	4.90	763.3	-6.75	4.74	730.0	-6.74	4.59	698.1
MAY 18 JUL 27	-6.78	5.27	849.9	-6.78	5.09	818.3	-6.78	4.92	786.8	-6.78	4.78	756.2	-6.78	4.64	726.8
MAY 3 AUG 10	-6.62	5.26	870.1	-6.62	5.10	844.0	-6.62	4.95	817.3	-6.62	4.82	790.9	-6.62	4.70	764.9
APR 19 AUG 25	-6.43	5.26	889.3	-6.43	5.12	870.1	-6.43	4.99	849.4	-6.43	4.88	828.1	-6.43	4.77	806.7
APR 4 SEP 9	-6.22	5.25	903.3	-6.22	5.14	891.8	-6.22	5.03	878.0	-6.22	4.93	862.6	-6.22	4.85	846.4
MAR 21 SEP 23	-6.00	5.24	908.0	-6.00	5.15	904.8	-6.00	5.07	898.2	-6.00	5.00	889.3	-6.00	4.93	878.7
MAR 7 OCT 8	-5.78	5.24	902.8	-5.78	5.17	907.7	-5.78	5.11	908.3	-5.78	5.06	905.7	-5.78	5.01	900.9
FEB 20 OCT 22	-5.57	5.23	888.6	-5.57	5.19	900.8	-5.57	5.15	908.0	-5.57	5.12	911.4	-5.57	5.09	911.8
FEB 7 NOV 5	-5.38	5.22	868.0	-5.38	5.21	886.4	-5.38	5.19	899.3	-5.38	5.17	907.8	-5.38	5.16	912.9
JAN 23 NOV 19	-5.22	5.22	846.3	-5.22	5.22	869.5	-5.22	5.22	886.8	-5.22	5.22	899.3	-5.22	5.22	908.1
JAN 10 DEC 3	-5.10	5.10	828.0	-5.10	5.10	854.4	-5.10	5.10	874.6	-5.10	5.10	889.9	-5.10	5.10	901.2
DEC 22	-5.03	5.03	816.0	-5.03	5.03	844.0	-5.03	5.03	865.9	-5.03	5.03	882.7	-5.03	5.03	895.3
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	315.533		.6003	313.884		.5972	311.166		.5920	307.719		.5855	303.779		.5780

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 30 N
ASPECT NE - NW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 34.0		ALPHA 4.9	THETA 37.6		ALPHA 10.1	THETA 40.9		ALPHA 15.6	THETA 43.8		ALPHA 21.3	THETA 46.1		ALPHA 27.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.81	1012.0	-6.97	6.63	1009.7	-6.97	6.44	999.0	-6.97	6.22	981.6	-6.97	5.98	959.2
JUN 1 JUL 12	-6.90	6.73	998.7	-6.90	6.53	993.5	-6.90	6.32	980.4	-6.90	6.09	961.0	-6.90	5.84	937.0
MAY 18 JUL 27	-6.78	6.59	974.8	-6.78	6.37	964.9	-6.78	6.14	947.8	-6.78	5.89	925.0	-6.78	5.62	898.4
MAY 3 AUG 10	-6.62	6.40	938.6	-6.62	6.15	922.4	-6.62	5.89	899.8	-6.62	5.61	872.7	-6.62	5.31	842.8
APR 19 AUG 25	-6.43	6.17	889.7	-6.43	5.90	866.0	-6.43	5.60	837.3	-6.43	5.29	805.4	-6.43	4.96	771.9
APR 4 SEP 9	-6.22	5.93	829.6	-6.22	5.62	798.2	-6.22	5.29	763.4	-6.22	4.94	726.7	-6.22	4.58	690.0
MAR 21 SEP 23	-6.00	5.68	759.4	-6.00	5.33	720.8	-6.00	4.96	680.3	-6.00	4.58	639.7	-6.00	4.19	600.4
MAR 7 OCT 8	-5.78	5.42	684.2	-5.78	5.04	639.4	-5.78	4.63	594.4	-5.78	4.22	550.7	-5.78	3.80	509.9
FEB 20 OCT 22	-5.57	5.18	609.6	-5.57	4.76	560.0	-5.57	4.32	511.7	-5.57	3.87	466.2	-5.57	3.42	424.8
FEB 7 NOV 5	-5.38	4.95	540.7	-5.38	4.50	487.8	-5.38	4.03	437.5	-5.38	3.55	391.4	-5.38	3.06	350.3
JAN 23 NOV 19	-5.22	4.76	484.1	-5.22	4.28	429.2	-5.22	3.78	378.0	-5.22	3.27	331.9	-5.22	2.76	291.6
JAN 10 DEC 3	-5.10	4.62	443.8	-5.10	4.12	387.8	-5.10	3.60	336.4	-5.10	3.06	290.7	-5.10	2.53	251.4
DEC 22	-5.03	4.54	420.1	-5.03	4.02	363.7	-5.03	3.48	312.3	-5.03	2.94	267.0	-5.03	2.40	228.3
	YEAR 271.126		R.I. .5158	YEAR 258.854		R.I. .4925	YEAR 245.894		R.I. .4678	YEAR 232.802		R.I. .4429	YEAR 220.074		R.I. .4187

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 48.1		ALPHA 33.0	THETA 49.5		ALPHA 38.7	THETA 50.6		ALPHA 44.1	THETA 51.4		ALPHA 49.3	THETA 51.9		ALPHA 54.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	5.73	933.6	-6.97	5.46	906.4	-6.97	5.19	878.8	-6.97	4.91	851.9	-6.97	4.64	826.0
JUN 1 JUL 12	-6.90	5.58	910.2	-6.90	5.30	882.1	-6.90	5.02	854.0	-6.90	4.74	826.7	-6.90	4.46	800.7
MAY 18 JUL 27	-6.78	5.33	869.7	-6.78	5.04	840.3	-6.78	4.74	811.4	-6.78	4.45	783.7	-6.78	4.17	757.5
MAY 3 AUG 10	-6.62	5.01	811.7	-6.62	4.69	780.7	-6.62	4.38	750.9	-6.62	4.08	722.9	-6.62	3.78	696.8
APR 19 AUG 25	-6.43	4.63	738.4	-6.43	4.29	706.0	-6.43	3.96	675.5	-6.43	3.65	647.4	-6.43	3.34	621.7
APR 4 SEP 9	-6.22	4.22	654.5	-6.22	3.86	621.1	-6.22	3.52	590.4	-6.22	3.19	562.7	-6.22	2.88	537.8
MAR 21 SEP 23	-6.00	3.80	563.6	-6.00	3.42	529.9	-6.00	3.06	499.7	-6.00	2.72	473.0	-6.00	2.40	449.3
MAR 7 OCT 8	-5.78	3.38	472.6	-5.78	2.98	439.4	-5.78	2.60	410.3	-5.78	2.24	385.1	-5.78	1.91	363.2
FEB 20 OCT 22	-5.57	2.97	388.0	-5.57	2.55	356.0	-5.57	2.15	328.6	-5.57	1.78	305.3	-5.57	1.45	285.5
FEB 7 NOV 5	-5.38	2.60	314.6	-5.38	2.15	284.3	-5.38	1.73	258.8	-5.38	1.35	237.7	-5.38	1.01	220.0
JAN 23 NOV 19	-5.22	2.27	257.4	-5.22	1.80	228.8	-5.22	1.37	205.4	-5.22	.98	186.2	-5.22	.63	170.5
JAN 10 DEC 3	-5.10	2.02	218.4	-5.10	1.54	191.4	-5.10	1.09	169.5	-5.10	.69	151.9	-5.10	.33	137.8
DEC 22	-5.03	1.87	196.3	-5.03	1.38	170.2	-5.03	.92	149.4	-5.03	.52	132.8	-5.03	.15	119.6
	YEAR 208.083		R.I. .3959	YEAR 197.037		R.I. .3749	YEAR 187.059		R.I. .3559	YEAR 178.158		R.I. .3390	YEAR 170.214		R.I. .3238

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 30 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 25.9		ALPHA 4.5	THETA 21.7		ALPHA 8.6	THETA 17.6		ALPHA 12.3	THETA 13.7		ALPHA 15.7	THETA 10.0		ALPHA 18.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.51	991.0	-6.97	6.09	972.3	-6.97	5.71	949.5	-6.97	5.36	923.7	-6.97	5.04	895.8
JUN 1 JUL 12	-6.90	6.45	984.0	-6.90	6.04	968.3	-6.90	5.67	948.4	-6.90	5.33	925.1	-6.90	5.02	899.4
MAY 18 JUL 27	-6.78	6.35	970.8	-6.78	5.96	960.2	-6.78	5.61	945.1	-6.78	5.28	926.1	-6.78	4.99	904.3
MAY 3 AUG 10	-6.62	6.22	949.3	-6.62	5.85	945.8	-6.62	5.52	937.3	-6.62	5.21	924.3	-6.62	4.94	907.9
APR 19 AUG 25	-6.43	6.06	917.7	-6.43	5.72	922.7	-6.43	5.41	922.2	-6.43	5.13	916.5	-6.43	4.88	906.7
APR 4 SEP 9	-6.22	5.88	876.0	-6.22	5.58	890.2	-6.22	5.30	898.3	-6.22	5.05	900.6	-6.22	4.82	898.1
MAR 21 SEP 23	-6.00	5.70	823.8	-6.00	5.43	847.2	-6.00	5.18	864.0	-6.00	4.95	874.4	-6.00	4.75	879.3
MAR 7 OCT 8	-5.78	5.52	764.9	-5.78	5.28	796.7	-5.78	5.06	821.5	-5.78	4.86	839.6	-5.78	4.69	851.6
FEB 20 OCT 22	-5.57	5.34	703.7	-5.57	5.13	742.6	-5.57	4.94	774.3	-5.57	4.77	799.1	-5.57	4.62	817.2
FEB 7 NOV 5	-5.38	5.18	645.0	-5.38	5.00	689.4	-5.38	4.84	726.6	-5.38	4.69	756.7	-5.38	4.56	779.9
JAN 23 NOV 19	-5.22	5.05	595.3	-5.22	4.89	643.5	-5.22	4.75	684.8	-5.22	4.63	718.7	-5.22	4.52	745.7
JAN 10 DEC 3	-5.10	4.95	559.1	-5.10	4.81	609.7	-5.10	4.69	653.4	-5.10	4.58	689.9	-5.10	4.48	719.4
DEC 22	-5.03	4.89	537.4	-5.03	4.76	589.4	-5.03	4.65	634.4	-5.03	4.55	672.2	-5.03	4.46	703.0
	YEAR 291.321		R.I. .5543	YEAR 298.424		R.I. .5678	YEAR 303.331		R.I. .5771	YEAR 306.156		R.I. .5825	YEAR 307.142		R.I. .5844

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 6.5		ALPHA 21.5	THETA 3.3		ALPHA 24.0	THETA .4		ALPHA 26.2	THETA -2.2		ALPHA 28.3	THETA -4.6		ALPHA 30.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	4.76	866.9	-6.97	4.50	837.8	-6.97	4.26	809.5	-6.97	4.05	782.3	-6.97	3.86	756.3
JUN 1 JUL 12	-6.90	4.74	872.5	-6.90	4.49	845.2	-6.90	4.26	818.3	-6.90	4.06	792.3	-6.90	3.87	767.4
MAY 18 JUL 27	-6.78	4.72	880.7	-6.78	4.48	856.3	-6.78	4.26	831.9	-6.78	4.07	808.0	-6.78	3.89	785.0
MAY 3 AUG 10	-6.62	4.69	889.1	-6.62	4.46	868.8	-6.62	4.26	848.0	-6.62	4.08	827.2	-6.62	3.91	806.7
APR 19 AUG 25	-6.43	4.65	893.7	-6.43	4.44	878.6	-6.43	4.26	862.2	-6.43	4.09	845.2	-6.43	3.93	828.0
APR 4 SEP 9	-6.22	4.61	891.6	-6.22	4.42	882.1	-6.22	4.25	870.7	-6.22	4.10	858.0	-6.22	3.96	844.7
MAR 21 SEP 23	-6.00	4.57	879.5	-6.00	4.40	876.1	-6.00	4.25	869.9	-6.00	4.12	861.9	-6.00	3.99	852.5
MAR 7 OCT 8	-5.78	4.52	858.2	-5.78	4.38	860.6	-5.78	4.25	859.6	-5.78	4.13	856.1	-5.78	4.02	850.8
FEB 20 OCT 22	-5.57	4.48	829.6	-5.57	4.36	837.1	-5.57	4.25	840.8	-5.57	4.14	841.6	-5.57	4.05	840.0
FEB 7 NOV 5	-5.38	4.45	797.0	-5.38	4.34	809.0	-5.38	4.24	816.6	-5.38	4.16	820.9	-5.38	4.08	822.7
JAN 23 NOV 19	-5.22	4.41	766.4	-5.22	4.32	781.6	-5.22	4.24	792.4	-5.22	4.17	799.4	-5.22	4.10	803.7
JAN 10 DEC 3	-5.10	4.39	742.4	-5.10	4.31	759.8	-5.10	4.24	772.6	-5.10	4.18	781.5	-5.10	4.12	787.5
DEC 22	-5.03	4.38	727.3	-5.03	4.30	746.0	-5.03	4.24	759.9	-5.03	4.18	769.9	-5.03	4.13	776.9
	YEAR 306.610		R.I. .5834	YEAR 304.899		R.I. .5801	YEAR 302.331		R.I. .5752	YEAR 299.186		R.I. .5692	YEAR 295.656		R.I. .5625

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 30 N
ASPECT ENE - WNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	32.0	6.2		33.7	12.6		35.0	18.9		36.0	25.1		36.5	31.0	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.64	1007.6	-6.97	6.29	1003.0	-6.97	5.92	992.4	-6.97	5.55	977.0	-6.97	5.19	958.5
JUN 1 JUL 12	-6.90	6.56	995.8	-6.90	6.20	989.9	-6.90	5.83	978.2	-6.90	5.46	962.1	-6.90	5.10	943.1
MAY 18 JUL 27	-6.78	6.43	974.5	-6.78	6.06	966.3	-6.78	5.69	952.9	-6.78	5.31	935.6	-6.78	4.94	915.8
MAY 3 AUG 10	-6.62	6.25	941.8	-6.62	5.88	930.6	-6.62	5.49	915.0	-6.62	5.11	896.1	-6.62	4.73	875.4
APR 19 AUG 25	-6.43	6.05	896.9	-6.43	5.65	882.3	-6.43	5.26	864.1	-6.43	4.86	843.6	-6.43	4.48	821.8
APR 4 SEP 9	-6.22	5.82	841.1	-6.22	5.41	822.9	-6.22	5.00	802.2	-6.22	4.60	780.1	-6.22	4.22	757.6
MAR 21 SEP 23	-6.00	5.58	775.1	-6.00	5.16	753.5	-6.00	4.74	730.6	-6.00	4.33	707.3	-6.00	3.94	684.3
MAR 7 OCT 8	-5.78	5.35	703.7	-5.78	4.91	679.3	-5.78	4.47	654.6	-5.78	4.05	630.4	-5.78	3.66	607.5
FEB 20 OCT 22	-5.57	5.12	632.1	-5.57	4.67	605.5	-5.57	4.22	579.7	-5.57	3.79	555.2	-5.57	3.39	532.6
FEB 7 NOV 5	-5.38	4.91	565.6	-5.38	4.45	537.5	-5.38	3.99	511.0	-5.38	3.55	486.6	-5.38	3.14	464.6
JAN 23 NOV 19	-5.22	4.74	510.5	-5.22	4.26	481.6	-5.22	3.79	454.9	-5.22	3.34	430.8	-5.22	2.93	409.4
JAN 10 DEC 3	-5.10	4.61	471.0	-5.10	4.12	441.7	-5.10	3.64	415.1	-5.10	3.19	391.3	-5.10	2.78	370.6
DEC 22	-5.03	4.53	447.8	-5.03	4.04	418.3	-5.03	3.56	391.7	-5.03	3.10	368.3	-5.03	2.68	347.9
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	276.045	.5252		269.057	.5119		261.507	.4975		253.722	.4827		245.985	.4680	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	36.8	36.4		36.8	41.5		36.7	46.0		36.4	50.2		36.0	53.9	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	4.84	938.1	-6.97	4.50	916.9	-6.97	4.19	895.8	-6.97	3.90	875.4	-6.97	3.64	855.8
JUN 1 JUL 12	-6.90	4.74	922.4	-6.90	4.41	901.1	-6.90	4.10	880.0	-6.90	3.81	859.7	-6.90	3.55	840.3
MAY 18 JUL 27	-6.78	4.59	894.8	-6.78	4.25	873.3	-6.78	3.94	852.3	-6.78	3.66	832.2	-6.78	3.39	813.0
MAY 3 AUG 10	-6.62	4.37	853.8	-6.62	4.04	832.3	-6.62	3.73	811.5	-6.62	3.45	791.7	-6.62	3.19	773.0
APR 19 AUG 25	-6.43	4.12	799.9	-6.43	3.79	778.5	-6.43	3.48	758.0	-6.43	3.20	738.8	-6.43	2.95	720.8
APR 4 SEP 9	-6.22	3.85	735.5	-6.22	3.52	714.4	-6.22	3.21	694.5	-6.22	2.93	676.1	-6.22	2.68	659.1
MAR 21 SEP 23	-6.00	3.57	662.5	-6.00	3.24	641.9	-6.00	2.93	623.0	-6.00	2.66	605.6	-6.00	2.41	589.7
MAR 7 OCT 8	-5.78	3.29	586.1	-5.78	2.95	566.5	-5.78	2.65	548.6	-5.78	2.38	532.5	-5.78	2.14	517.9
FEB 20 OCT 22	-5.57	3.02	512.0	-5.57	2.68	493.4	-5.57	2.38	476.8	-5.57	2.11	462.1	-5.57	1.87	448.8
FEB 7 NOV 5	-5.38	2.77	444.9	-5.38	2.43	427.6	-5.38	2.13	412.3	-5.38	1.87	398.8	-5.38	1.63	386.9
JAN 23 NOV 19	-5.22	2.56	390.7	-5.22	2.22	374.4	-5.22	1.92	360.3	-5.22	1.66	347.9	-5.22	1.42	337.1
JAN 10 DEC 3	-5.10	2.40	352.6	-5.10	2.06	337.2	-5.10	1.76	323.9	-5.10	1.50	312.4	-5.10	1.27	302.3
DEC 22	-5.03	2.31	330.5	-5.03	1.97	315.5	-5.03	1.67	302.7	-5.03	1.41	291.7	-5.03	1.18	282.2
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	238.518	.4538		231.446	.4403		224.862	.4278		218.798	.4163		213.203	.4056	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 30 N
ASPECT ESE - WSW

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	27.7	6.0	25.2	11.6	22.6	16.7	19.9	21.4	17.4	25.7

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.48	996.6	-6.97	6.02	984.1	-6.97	5.58	968.2	-6.97	5.18	949.5	-6.97	4.81	928.9
JUN 1 JUL 12	-6.90	6.42	988.2	-6.90	5.96	977.5	-6.90	5.53	963.2	-6.90	5.13	946.1	-6.90	4.77	926.9
MAY 18 JUL 27	-6.78	6.31	972.6	-6.78	5.86	964.8	-6.78	5.44	953.4	-6.78	5.06	938.9	-6.78	4.71	922.1
MAY 3 AUG 10	-6.62	6.16	947.8	-6.62	5.73	944.1	-6.62	5.33	936.5	-6.62	4.96	925.7	-6.62	4.62	912.3
APR 19 AUG 25	-6.43	5.99	912.2	-6.43	5.58	913.4	-6.43	5.19	910.6	-6.43	4.84	904.2	-6.43	4.52	894.8
APR 4 SEP 9	-6.22	5.80	866.3	-6.22	5.41	872.7	-6.22	5.04	875.0	-6.22	4.71	873.4	-6.22	4.41	868.5
MAR 21 SEP 23	-6.00	5.60	810.0	-6.00	5.23	821.6	-6.00	4.89	829.0	-6.00	4.57	832.3	-6.00	4.29	832.0
MAR 7 OCT 8	-5.78	5.40	747.3	-5.78	5.05	763.7	-5.78	4.73	775.9	-5.78	4.44	783.7	-5.78	4.17	787.7
FEB 20 OCT 22	-5.57	5.22	682.9	-5.57	4.88	703.4	-5.57	4.58	719.5	-5.57	4.31	731.3	-5.57	4.06	739.1
FEB 7 NOV 5	-5.38	5.04	621.7	-5.38	4.73	645.3	-5.38	4.44	664.7	-5.38	4.19	679.7	-5.38	3.96	690.4
JAN 23 NOV 19	-5.22	4.90	570.3	-5.22	4.60	596.1	-5.22	4.33	617.8	-5.22	4.09	635.0	-5.22	3.87	648.0
JAN 10 DEC 3	-5.10	4.79	533.0	-5.10	4.50	560.2	-5.10	4.24	583.3	-5.10	4.01	602.0	-5.10	3.81	616.4
DEC 22	-5.03	4.72	510.9	-5.03	4.44	538.8	-5.03	4.19	562.6	-5.03	3.97	582.0	-5.03	3.77	597.3

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
286.964	.5460	290.393	.5525	292.352	.5562	292.920	.5573	292.270	.5561

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	15.0	29.5	12.7	32.9	10.6	36.0	8.6	38.7	6.8	41.1

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	4.48	907.3	-6.97	4.18	885.3	-6.97	3.91	863.5	-6.97	3.67	842.5	-6.97	3.46	822.3
JUN 1 JUL 12	-6.90	4.45	906.5	-6.90	4.15	885.6	-6.90	3.89	864.9	-6.90	3.65	844.7	-6.90	3.44	825.2
MAY 18 JUL 27	-6.78	4.39	903.8	-6.78	4.11	884.8	-6.78	3.85	865.7	-6.78	3.62	846.9	-6.78	3.42	828.7
MAY 3 AUG 10	-6.62	4.32	897.0	-6.62	4.05	880.7	-6.62	3.80	863.9	-6.62	3.58	847.1	-6.62	3.38	830.6
APR 19 AUG 25	-6.43	4.23	883.3	-6.43	3.97	870.2	-6.43	3.74	856.3	-6.43	3.53	842.0	-6.43	3.35	827.7
APR 4 SEP 9	-6.22	4.14	861.0	-6.22	3.89	851.6	-6.22	3.67	840.9	-6.22	3.48	829.5	-6.22	3.30	817.7
MAR 21 SEP 23	-6.00	4.03	828.7	-6.00	3.81	823.0	-6.00	3.60	815.7	-6.00	3.42	807.2	-6.00	3.26	798.1
MAR 7 OCT 8	-5.78	3.93	788.3	-5.78	3.72	786.3	-5.78	3.53	782.2	-5.78	3.36	776.8	-5.78	3.21	770.3
FEB 20 OCT 22	-5.57	3.84	743.2	-5.57	3.64	744.4	-5.57	3.47	743.3	-5.57	3.31	740.5	-5.57	3.17	736.5
FEB 7 NOV 5	-5.38	3.75	697.5	-5.38	3.57	701.4	-5.38	3.40	702.8	-5.38	3.26	702.2	-5.38	3.13	700.3
JAN 23 NOV 19	-5.22	3.68	657.2	-5.22	3.50	663.1	-5.22	3.35	666.4	-5.22	3.22	667.6	-5.22	3.10	667.2
JAN 10 DEC 3	-5.10	3.62	627.0	-5.10	3.46	634.3	-5.10	3.32	638.8	-5.10	3.19	641.2	-5.10	3.07	641.9
DEC 22	-5.03	3.59	608.6	-5.03	3.43	616.6	-5.03	3.29	621.9	-5.03	3.17	624.9	-5.03	3.06	626.2

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
290.630	.5529	288.236	.5484	285.317	.5428	282.069	.5367	278.618	.5301

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 30 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 29.8		ALPHA 6.6	THETA 29.4		ALPHA 13.0	THETA 28.6		ALPHA 19.1	THETA 27.7		ALPHA 24.8	THETA 26.6		ALPHA 30.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	6.52	1002.4	-6.97	6.08	994.7	-6.97	5.64	982.9	-6.97	5.23	967.9	-6.97	4.84	950.6
JUN 1 JUL 12	-6.90	6.45	992.3	-6.90	6.01	984.9	-6.90	5.57	973.4	-6.90	5.16	958.8	-6.90	4.78	942.1
MAY 18 JUL 27	-6.78	6.33	973.8	-6.78	5.89	966.8	-6.78	5.46	956.0	-6.78	5.05	942.2	-6.78	4.67	926.3
MAY 3 AUG 10	-6.62	6.17	945.1	-6.62	5.73	938.7	-6.62	5.31	928.8	-6.62	4.91	916.1	-6.62	4.53	901.4
APR 19 AUG 25	-6.43	5.98	904.9	-6.43	5.55	899.3	-6.43	5.13	890.5	-6.43	4.73	879.2	-6.43	4.37	866.0
APR 4 SEP 9	-6.22	5.78	854.1	-6.22	5.34	849.3	-6.22	4.93	841.8	-6.22	4.54	832.0	-6.22	4.19	820.6
MAR 21 SEP 23	-6.00	5.56	792.9	-6.00	5.13	789.1	-6.00	4.73	782.9	-6.00	4.35	774.9	-6.00	4.00	765.3
MAR 7 OCT 8	-5.78	5.34	725.8	-5.78	4.92	722.9	-5.78	4.52	718.1	-5.78	4.15	711.7	-5.78	3.81	704.1
FEB 20 OCT 22	-5.57	5.14	657.8	-5.57	4.72	655.7	-5.57	4.32	652.2	-5.57	3.96	647.4	-5.57	3.63	641.4
FEB 7 NOV 5	-5.38	4.95	593.9	-5.38	4.53	592.6	-5.38	4.14	590.1	-5.38	3.79	586.6	-5.38	3.47	582.1
JAN 23 NOV 19	-5.22	4.79	540.7	-5.22	4.37	539.8	-5.22	3.99	538.2	-5.22	3.64	535.7	-5.22	3.33	532.4
JAN 10 DEC 3	-5.10	4.67	502.3	-5.10	4.26	501.8	-5.10	3.88	500.8	-5.10	3.53	499.0	-5.10	3.22	496.4
DEC 22	-5.03	4.60	479.6	-5.03	4.19	479.3	-5.03	3.81	478.6	-5.03	3.47	477.1	-5.03	3.16	475.0
	YEAR 281.620		R.I. .5358	YEAR 280.171		R.I. .5330	YEAR 277.870		R.I. .5287	YEAR 274.862		R.I. .5229	YEAR 271.314		R.I. .5162

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 25.4		ALPHA 34.7	THETA 24.2		ALPHA 39.0	THETA 23.0		ALPHA 42.7	THETA 21.8		ALPHA 46.1	THETA 20.7		ALPHA 49.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.97	4.48	932.2	-6.97	4.15	913.2	-6.97	3.86	894.2	-6.97	3.60	875.8	-6.97	3.36	858.1
JUN 1 JUL 12	-6.90	4.42	924.1	-6.90	4.10	905.6	-6.90	3.81	887.2	-6.90	3.55	869.2	-6.90	3.31	851.8
MAY 18 JUL 27	-6.78	4.32	909.2	-6.78	4.01	891.6	-6.78	3.72	873.9	-6.78	3.47	856.7	-6.78	3.23	840.1
MAY 3 AUG 10	-6.62	4.19	885.6	-6.62	3.88	869.1	-6.62	3.60	852.7	-6.62	3.35	836.6	-6.62	3.13	820.9
APR 19 AUG 25	-6.43	4.04	851.7	-6.43	3.73	836.9	-6.43	3.46	821.9	-6.43	3.22	807.2	-6.43	3.00	792.9
APR 4 SEP 9	-6.22	3.86	808.2	-6.22	3.57	795.1	-6.22	3.31	781.8	-6.22	3.08	768.7	-6.22	2.87	755.9
MAR 21 SEP 23	-6.00	3.69	754.8	-6.00	3.40	743.6	-6.00	3.15	732.2	-6.00	2.93	720.9	-6.00	2.73	709.7
MAR 7 OCT 8	-5.78	3.51	695.4	-5.78	3.23	686.2	-5.78	2.99	676.7	-5.78	2.78	667.1	-5.78	2.58	657.6
FEB 20 OCT 22	-5.57	3.34	634.6	-5.57	3.07	627.1	-5.57	2.84	619.4	-5.57	2.63	611.4	-5.57	2.45	603.5
FEB 7 NOV 5	-5.38	3.18	576.8	-5.38	2.92	570.9	-5.38	2.70	564.7	-5.38	2.50	558.2	-5.38	2.32	551.7
JAN 23 NOV 19	-5.22	3.05	528.3	-5.22	2.80	523.6	-5.22	2.58	518.5	-5.22	2.39	513.2	-5.22	2.22	507.7
JAN 10 DEC 3	-5.10	2.95	493.1	-5.10	2.71	489.3	-5.10	2.49	485.0	-5.10	2.31	480.5	-5.10	2.14	475.8
DEC 22	-5.03	2.89	472.2	-5.03	2.65	468.8	-5.03	2.44	465.0	-5.03	2.26	460.9	-5.03	2.10	456.7
	YEAR 267.402		R.I. .5088	YEAR 263.277		R.I. .5009	YEAR 259.078		R.I. .4929	YEAR 254.914		R.I. .4850	YEAR 250.825		R.I. .4772

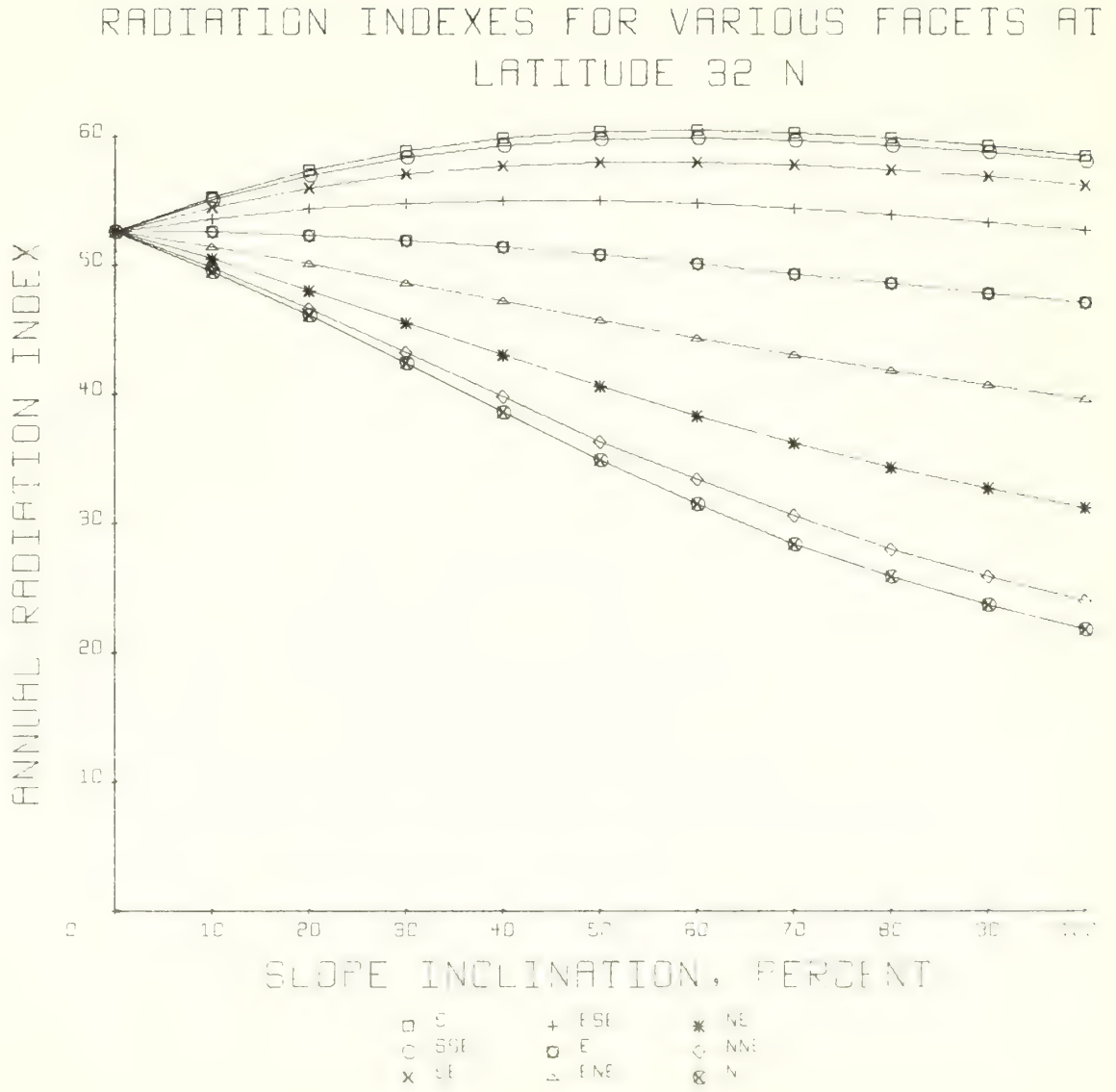
NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN

HORIZONTAL SURFACE

LATITUDE 32 N

		SR	SS	LY
JUN 22		-7.05	7.05	1010.4
JUN 1	JUL 12	-6.97	6.97	998.6
MAY 18	JUL 27	-6.84	6.84	977.3
MAY 3	AUG 10	-6.67	6.67	944.6
APR 19	AUG 25	-6.46	6.46	899.7
APR 4	SEP 9	-6.24	6.24	843.8
MAR 21	SEP 23	-6.00	6.00	777.7
MAR 7	OCT 8	-5.76	5.76	706.2
FEB 20	OCT 22	-5.54	5.54	634.5
FEB 7	NOV 5	-5.33	5.33	567.8
JAN 23	NOV 19	-5.16	5.16	512.6
JAN 10	DEC 3	-5.03	5.03	473.1
DEC 22		-4.95	4.95	449.7

YEAR	R.I.
276.961	.5269



LATITUDE 32 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	37.7		0.0	43.3		0.0	48.7		0.0	53.8		0.0	58.6		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	7.05	1019.2	-7.05	7.05	1018.0	-7.05	7.05	1007.7	-7.05	7.05	989.7	-7.05	7.05	965.9
JUN 1 JUL 12	-6.97	6.97	1002.8	-6.97	6.97	997.3	-6.97	6.97	982.9	-6.97	6.97	961.4	-6.97	6.97	934.4
MAY 18 JUL 27	-6.84	6.84	973.7	-6.84	6.84	960.9	-6.84	6.84	939.9	-6.84	6.84	912.4	-6.84	6.84	880.1
MAY 3 AUG 10	-6.67	6.67	930.5	-6.67	6.67	907.7	-6.67	6.67	877.7	-6.67	6.67	842.1	-6.67	6.67	802.8
APR 19 AUG 25	-6.46	6.46	873.2	-6.46	6.46	838.8	-6.46	6.46	798.2	-6.46	6.46	753.2	-6.46	6.46	705.8
APR 4 SEP 9	-6.24	6.24	804.2	-6.24	6.24	757.7	-6.24	6.24	706.1	-6.24	6.24	651.5	-6.24	6.24	595.8
MAR 21 SEP 23	-6.00	6.00	725.5	-6.00	6.00	667.3	-6.00	6.00	605.3	-6.00	6.00	541.6	-6.00	6.00	478.3
MAR 7 OCT 8	-5.71	5.71	642.7	-5.64	5.64	574.5	-5.57	5.57	504.0	-5.48	5.48	433.3	-5.38	5.38	364.5
FEB 20 OCT 22	-5.43	5.43	562.1	-5.30	5.30	486.5	-5.15	5.15	410.1	-4.98	4.98	335.5	-4.77	4.77	264.5
FEB 7 NOV 5	-5.17	5.17	489.0	-4.98	4.98	408.5	-4.77	4.77	329.1	-4.51	4.51	253.3	-4.19	4.19	183.3
JAN 23 NOV 19	-4.95	4.95	429.7	-4.71	4.71	346.5	-4.43	4.43	266.2	-4.09	4.09	191.3	-3.66	3.66	124.3
JAN 10 DEC 3	-4.79	4.79	387.9	-4.51	4.51	303.6	-4.18	4.18	223.5	-3.77	3.77	150.4	-3.25	3.25	87.1
DEC 22	-4.69	4.69	363.5	-4.39	4.39	279.0	-4.02	4.02	199.4	-3.57	3.57	127.8	-2.98	2.98	67.2
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	260.592		.4958	242.336		.4611	222.960		.4242	203.232		.3867	183.923		.3499

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	63.0		0.0	67.0		0.0	70.7		0.0	74.0		0.0	77.0		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	7.05	937.9	-7.05	7.05	907.4	-7.05	7.05	875.7	-7.05	7.05	844.0	-7.05	7.05	812.7
JUN 1 JUL 12	-6.97	6.97	903.7	-6.97	6.97	870.8	-6.97	6.97	837.2	-6.97	6.97	803.9	-6.97	6.97	771.2
MAY 18 JUL 27	-6.84	6.84	844.9	-6.84	6.84	808.3	-6.84	6.84	771.5	-6.84	6.84	735.5	-6.84	6.84	700.6
MAY 3 AUG 10	-6.67	6.67	761.5	-6.67	6.67	719.8	-6.67	6.67	678.7	-6.67	6.67	639.2	-6.67	6.67	601.4
APR 19 AUG 25	-6.46	6.46	657.7	-6.46	6.46	610.2	-6.46	6.46	564.3	-6.46	6.46	520.9	-6.46	6.46	479.8
APR 4 SEP 9	-6.24	6.24	540.7	-6.24	6.24	487.4	-6.24	6.24	436.8	-6.24	6.24	389.6	-6.24	6.24	345.4
MAR 21 SEP 23	-6.00	6.00	416.8	-6.00	6.00	358.3	-6.00	6.00	303.6	-6.00	6.00	253.0	-6.00	6.00	206.3
MAR 7 OCT 8	-5.26	5.26	299.0	-5.10	5.10	238.0	-4.91	4.91	182.2	-4.66	4.66	132.0	-4.31	4.31	87.2
FEB 20 OCT 22	-4.52	4.52	199.0	-4.20	4.20	139.9	-3.78	3.78	88.4	-3.19	3.19	45.5	-2.22	2.22	13.0
FEB 7 NOV 5	-3.79	3.79	121.0	-3.26	3.26	68.0	-2.49	2.49	26.5	-.91	.91	1.1	0.00	0.00	0.0
JAN 23 NOV 19	-3.10	3.10	67.6	-2.28	2.28	23.9	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	-2.52	2.52	36.4	-1.21	1.21	3.6	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-2.10	2.10	21.3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	165.767		.3154	149.600		.2846	136.187		.2591	124.734		.2373	114.780		.2184

NOTE - FOR ASPECTS WITH WEST COMPONENTS. THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 32 N
ASPECT S -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 26.3		ALPHA 0.0	THETA 20.7		ALPHA 0.0	THETA 15.3		ALPHA 0.0	THETA 10.2		ALPHA 0.0	THETA 5.4		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.83	6.83	992.8	-6.63	6.63	968.0	-6.46	6.46	937.3	-6.30	6.30	901.9	-6.16	6.16	863.5
JUN 1 JUL 12	-6.77	6.77	985.5	-6.58	6.58	965.1	-6.42	6.42	938.2	-6.28	6.28	906.3	-6.15	6.15	871.1
MAY 18 JUL 27	-6.67	6.67	971.9	-6.51	6.51	958.6	-6.37	6.37	938.4	-6.24	6.24	912.6	-6.13	6.13	882.7
MAY 3 AUG 10	-6.53	6.53	949.8	-6.40	6.40	946.6	-6.29	6.29	935.8	-6.19	6.19	918.6	-6.10	6.10	896.4
APR 19 AUG 25	-6.36	6.36	917.5	-6.28	6.28	926.5	-6.20	6.20	927.2	-6.13	6.13	920.7	-6.07	6.07	908.2
APR 4 SEP 9	-6.19	6.19	875.1	-6.14	6.14	897.4	-6.10	6.10	910.9	-6.07	6.07	916.3	-6.04	6.04	914.9
MAR 21 SEP 23	-6.00	6.00	822.3	-6.00	6.00	858.0	-6.00	6.00	884.6	-6.00	6.00	902.6	-6.00	6.00	913.0
MAR 7 OCT 8	-5.76	5.76	762.8	-5.76	5.76	810.8	-5.76	5.76	849.7	-5.76	5.76	879.6	-5.76	5.76	901.2
FEB 20 OCT 22	-5.54	5.54	700.9	-5.54	5.54	759.2	-5.54	5.54	808.4	-5.54	5.54	848.4	-5.54	5.54	879.8
FEB 7 NOV 5	-5.33	5.33	641.6	-5.33	5.33	707.7	-5.33	5.33	764.9	-5.33	5.33	812.9	-5.33	5.33	851.9
JAN 23 NOV 19	-5.16	5.16	591.4	-5.16	5.16	662.9	-5.16	5.16	725.7	-5.16	5.16	779.3	-5.16	5.16	823.8
JAN 10 DEC 3	-5.03	5.03	554.8	-5.03	5.03	629.6	-5.03	5.03	695.8	-5.03	5.03	752.9	-5.03	5.03	800.8
DEC 22	-4.95	4.95	533.0	-4.95	4.95	609.4	-4.95	4.95	677.4	-4.95	4.95	736.3	-4.95	4.95	786.1
	YEAR 290.812		R.I. .5533	YEAR 301.771		R.I. .5741	YEAR 309.752		R.I. .5893	YEAR 314.922		R.I. .5992	YEAR 317.608		R.I. .6043

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 1.0		ALPHA 0.0	THETA -3.0		ALPHA 0.0	THETA -6.7		ALPHA 0.0	THETA -10.0		ALPHA 0.0	THETA -13.0		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.03	6.03	823.8	-5.91	5.91	783.9	-5.81	5.81	744.9	-5.71	5.71	707.5	-5.62	5.62	672.0
JUN 1 JUL 12	-6.03	6.03	834.0	-5.92	5.92	796.4	-5.82	5.82	759.4	-5.73	5.73	723.7	-5.64	5.64	689.5
MAY 18 JUL 27	-6.02	6.02	850.3	-5.93	5.93	816.8	-5.84	5.84	783.2	-5.76	5.76	750.4	-5.69	5.69	718.8
MAY 3 AUG 10	-6.02	6.02	870.8	-5.94	5.94	843.2	-5.88	5.88	814.8	-5.81	5.81	786.4	-5.75	5.75	758.5
APR 19 AUG 25	-6.01	6.01	891.3	-5.96	5.96	871.4	-5.91	5.91	849.6	-5.87	5.87	827.1	-5.83	5.83	804.3
APR 4 SEP 9	-6.01	6.01	908.0	-5.98	5.98	897.0	-5.96	5.96	883.3	-5.93	5.93	867.7	-5.91	5.91	851.1
MAR 21 SEP 23	-6.00	6.00	917.0	-6.00	6.00	915.8	-6.00	6.00	910.9	-6.00	6.00	903.2	-6.00	6.00	893.6
MAR 7 OCT 8	-5.76	5.76	915.7	-5.76	5.76	924.3	-5.76	5.76	928.0	-5.76	5.76	928.2	-5.76	5.76	925.6
FEB 20 OCT 22	-5.54	5.54	903.3	-5.54	5.54	920.2	-5.54	5.54	931.6	-5.54	5.54	938.7	-5.54	5.54	942.3
FEB 7 NOV 5	-5.33	5.33	882.7	-5.33	5.33	906.4	-5.33	5.33	924.0	-5.33	5.33	936.6	-5.33	5.33	945.5
JAN 23 NOV 19	-5.16	5.16	859.8	-5.16	5.16	888.4	-5.16	5.16	910.6	-5.16	5.16	927.4	-5.16	5.16	940.0
JAN 10 DEC 3	-5.03	5.03	840.2	-5.03	5.03	871.9	-5.03	5.03	897.0	-5.03	5.03	916.6	-5.03	5.03	931.7
DEC 22	-4.95	4.95	827.2	-4.95	4.95	860.6	-4.95	4.95	887.3	-4.95	4.95	908.4	-4.95	4.95	924.9
	YEAR 318.226		R.I. .6055	YEAR 317.219		R.I. .6035	YEAR 315.000		R.I. .5993	YEAR 311.934		R.I. .5935	YEAR 308.280		R.I. .5865

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 32 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	37.3		2.7	42.3		5.8	47.1		9.3	51.5		13.2	55.5		17.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	7.05	1018.2	-7.05	7.05	1015.9	-7.05	7.05	1004.7	-7.05	7.05	985.8	-7.05	7.05	961.1
JUN 1 JUL 12	-6.97	6.97	1002.1	-6.97	6.97	995.9	-6.97	6.97	980.9	-6.97	6.97	958.8	-6.97	6.97	931.2
MAY 18 JUL 27	-6.84	6.84	973.6	-6.84	6.84	960.7	-6.84	6.84	939.6	-6.84	6.84	912.0	-6.84	6.84	879.7
MAY 3 AUG 10	-6.67	6.63	931.2	-6.67	6.59	909.2	-6.67	6.54	879.9	-6.67	6.49	845.0	-6.67	6.42	806.4
APR 19 AUG 25	-6.46	6.38	874.9	-6.46	6.29	842.4	-6.46	6.18	803.8	-6.46	6.06	761.0	-6.46	5.91	715.8
APR 4 SEP 9	-6.24	6.10	807.1	-6.24	5.95	763.9	-6.24	5.79	716.0	-6.24	5.60	665.5	-6.24	5.38	614.2
MAR 21 SEP 23	-6.00	5.82	729.6	-6.00	5.61	676.3	-6.00	5.38	620.0	-6.00	5.12	562.9	-6.00	4.83	507.0
MAR 7 OCT 8	-5.76	5.53	647.9	-5.76	5.27	586.1	-5.76	4.97	523.1	-5.76	4.64	461.2	-5.76	4.28	402.3
FEB 20 OCT 22	-5.54	5.25	568.1	-5.54	4.94	499.8	-5.54	4.58	432.1	-5.54	4.18	367.3	-5.54	3.74	307.4
FEB 7 NOV 5	-5.33	5.00	495.5	-5.33	4.63	422.8	-5.33	4.22	352.4	-5.33	3.75	286.6	-5.33	3.23	227.3
JAN 23 NOV 19	-5.15	4.79	436.5	-5.15	4.37	361.3	-5.14	3.90	289.8	-5.13	3.37	224.3	-5.12	2.78	166.6
JAN 10 DEC 3	-4.99	4.63	394.8	-4.95	4.17	318.5	-4.90	3.66	246.9	-4.85	3.09	182.4	-4.77	2.43	126.8
DEC 22	-4.90	4.53	370.5	-4.83	4.06	293.8	-4.76	3.52	222.5	-4.67	2.91	159.0	-4.55	2.21	105.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	261.867		.4982	245.108		.4663	227.425		.4327	209.541		.3987	192.141		.3656

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	59.0		22.5	62.1		27.9	64.6		33.9	66.6		40.2	68.2		46.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	7.05	932.4	-7.05	7.05	901.3	-7.05	7.05	869.1	-7.05	7.05	836.9	-7.05	7.05	805.2
JUN 1 JUL 12	-6.97	6.97	900.0	-6.97	6.97	866.8	-6.97	6.97	832.9	-6.97	6.97	799.2	-6.97	6.97	766.3
MAY 18 JUL 27	-6.84	6.84	844.4	-6.84	6.84	807.7	-6.84	6.84	770.9	-6.84	6.84	734.8	-6.84	6.84	699.9
MAY 3 AUG 10	-6.67	6.35	765.9	-6.67	6.25	724.9	-6.67	6.14	684.6	-6.67	6.00	645.9	-6.67	5.83	609.0
APR 19 AUG 25	-6.46	5.75	670.0	-6.46	5.56	625.0	-6.46	5.34	582.0	-6.46	5.09	541.6	-6.46	4.80	504.0
APR 4 SEP 9	-6.24	5.13	564.0	-6.24	4.85	516.1	-6.24	4.54	471.6	-6.24	4.20	430.9	-6.24	3.83	394.1
MAR 21 SEP 23	-6.00	4.50	453.8	-6.00	4.14	404.6	-6.00	3.74	360.1	-6.00	3.32	320.7	-6.00	2.88	286.2
MAR 7 OCT 8	-5.76	3.87	347.9	-5.76	3.42	299.1	-5.76	2.94	256.5	-5.76	2.44	220.0	-5.76	1.92	189.2
FEB 20 OCT 22	-5.54	3.25	253.7	-5.54	2.72	207.0	-5.54	2.15	167.6	-5.54	1.55	135.4	-5.54	.95	109.5
FEB 7 NOV 5	-5.33	2.65	175.7	-5.33	2.02	132.5	-5.33	1.35	97.6	-5.33	.64	70.6	-5.33	-.08	50.4
JAN 23 NOV 19	-5.11	2.11	117.9	-5.10	1.38	78.7	-5.08	.57	48.7	-5.06	-.30	27.3	-5.02	-1.23	13.2
JAN 10 DEC 3	-4.68	1.68	81.2	-4.56	.84	45.9	-4.38	-.13	20.9	-4.08	-1.28	5.6	0.00	0.00	0.0
DEC 22	-4.40	1.40	61.7	-4.19	.46	29.6	-3.84	-.68	8.7	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	175.794		.3345	160.870		.3061	147.635		.2809	136.218		.2592	126.459		.2406

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 32 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 26.7		ALPHA 2.4	THETA 21.5		ALPHA 4.6	THETA 16.4		ALPHA 6.6	THETA 11.6		ALPHA 8.3	THETA 7.1		ALPHA 9.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.00	6.68	994.3	-6.96	6.35	971.9	-6.93	6.05	944.1	-6.90	5.79	912.2	-6.87	5.54	877.5
JUN 1 JUL 12	-6.94	6.62	986.7	-6.92	6.30	968.4	-6.89	6.02	944.3	-6.87	5.76	915.7	-6.85	5.53	884.0
MAY 18 JUL 27	-6.84	6.51	972.5	-6.84	6.22	960.9	-6.83	5.96	943.2	-6.83	5.72	920.3	-6.83	5.50	893.7
MAY 3 AUG 10	-6.67	6.37	949.7	-6.67	6.11	947.5	-6.67	5.88	938.5	-6.67	5.66	923.8	-6.67	5.47	904.5
APR 19 AUG 25	-6.46	6.21	916.4	-6.46	5.98	925.5	-6.46	5.78	927.2	-6.46	5.60	922.3	-6.46	5.43	912.0
APR 4 SEP 9	-6.24	6.03	872.9	-6.24	5.84	894.1	-6.24	5.67	907.3	-6.24	5.52	913.1	-6.24	5.38	912.6
MAR 21 SEP 23	-6.00	5.84	819.0	-6.00	5.69	852.1	-6.00	5.56	876.9	-6.00	5.44	893.6	-6.00	5.34	903.3
MAR 7 OCT 8	-5.76	5.65	758.4	-5.76	5.54	802.5	-5.76	5.45	838.0	-5.76	5.37	865.0	-5.76	5.29	884.2
FEB 20 OCT 22	-5.54	5.47	695.7	-5.54	5.40	749.0	-5.54	5.34	793.7	-5.54	5.29	829.6	-5.54	5.25	857.3
FEB 7 NOV 5	-5.33	5.30	635.8	-5.33	5.27	696.3	-5.33	5.25	748.2	-5.33	5.23	791.3	-5.33	5.21	826.0
JAN 23 NOV 19	-5.16	5.16	585.2	-5.16	5.16	650.7	-5.16	5.16	707.6	-5.16	5.16	756.2	-5.16	5.16	796.0
JAN 10 DEC 3	-5.03	5.03	548.4	-5.03	5.03	617.0	-5.03	5.03	677.3	-5.03	5.03	729.0	-5.03	5.03	772.1
DEC 22	-4.95	4.95	526.5	-4.95	4.95	596.6	-4.95	4.95	658.6	-4.95	4.95	712.0	-4.95	4.95	756.9
	YEAR 289.774		R.I. .5513	YEAR 299.931		R.I. .5706	YEAR 307.327		R.I. .5847	YEAR 312.106		R.I. .5938	YEAR 314.565		R.I. .5985

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 2.9		ALPHA 11.4	THETA -0.9		ALPHA 12.7	THETA -4.3		ALPHA 13.9	THETA -7.5		ALPHA 15.0	THETA -10.3		ALPHA 16.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.84	5.33	841.5	-6.82	5.13	805.3	-6.80	4.95	769.9	-6.78	4.78	735.9	-6.76	4.63	703.5
JUN 1 JUL 12	-6.84	5.32	850.6	-6.82	5.13	816.6	-6.81	4.96	783.1	-6.80	4.80	750.8	-6.78	4.65	719.8
MAY 18 JUL 27	-6.83	5.31	864.9	-6.82	5.13	834.9	-6.82	4.97	804.8	-6.82	4.83	775.4	-6.82	4.69	746.9
MAY 3 AUG 10	-6.67	5.30	882.2	-6.67	5.14	857.8	-6.67	4.99	832.7	-6.67	4.86	807.5	-6.67	4.74	782.7
APR 19 AUG 25	-6.46	5.28	897.5	-6.46	5.14	880.3	-6.46	5.02	861.3	-6.46	4.91	841.5	-6.46	4.80	821.3
APR 4 SEP 9	-6.24	5.26	907.1	-6.24	5.15	897.7	-6.24	5.05	885.7	-6.24	4.95	871.9	-6.24	4.87	857.1
MAR 21 SEP 23	-6.00	5.24	906.9	-6.00	5.15	905.8	-6.00	5.08	901.1	-6.00	5.00	893.9	-6.00	4.94	884.8
MAR 7 OCT 8	-5.76	5.22	896.7	-5.76	5.16	903.7	-5.76	5.10	906.2	-5.76	5.05	905.4	-5.76	5.00	902.1
FEB 20 OCT 22	-5.54	5.20	877.7	-5.54	5.17	891.9	-5.54	5.13	901.0	-5.54	5.10	906.1	-5.54	5.07	908.1
FEB 7 NOV 5	-5.33	5.19	852.9	-5.33	5.17	873.2	-5.33	5.16	887.9	-5.33	5.14	898.0	-5.33	5.13	904.7
JAN 23 NOV 19	-5.16	5.16	827.8	-5.16	5.16	852.7	-5.16	5.16	871.7	-5.16	5.16	885.6	-5.16	5.16	896.1
JAN 10 DEC 3	-5.03	5.03	807.1	-5.03	5.03	835.1	-5.03	5.03	856.9	-5.03	5.03	873.6	-5.03	5.03	886.2
DEC 22	-4.95	4.95	793.6	-4.95	4.95	823.2	-4.95	4.95	846.5	-4.95	4.95	864.7	-4.95	4.95	878.7
	YEAR 315.091		R.I. .5999	YEAR 314.094		R.I. .5976	YEAR 311.966		R.I. .5935	YEAR 309.046		R.I. .5880	YEAR 305.579		R.I. .5814

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 32 N
ASPECT NE - NW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	35.9		5.0	39.6		10.4	42.8		16.1	45.6		22.1	47.9		28.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	6.89	1015.4	-7.05	6.71	1011.2	-7.05	6.51	998.7	-7.05	6.29	979.5	-7.05	6.04	955.5
JUN 1 JUL 12	-6.97	6.80	1000.4	-6.97	6.61	993.3	-6.97	6.39	978.4	-6.97	6.15	957.2	-6.97	5.89	931.7
MAY 18 JUL 27	-6.84	6.65	973.8	-6.84	6.43	961.9	-6.84	6.19	942.9	-6.84	5.93	918.5	-6.84	5.65	890.5
MAY 3 AUG 10	-6.67	6.45	933.8	-6.67	6.20	915.6	-6.67	5.93	891.3	-6.67	5.63	862.6	-6.67	5.32	831.4
APR 19 AUG 25	-6.46	6.20	880.4	-6.46	5.92	854.9	-6.46	5.61	824.5	-6.46	5.29	791.2	-6.46	4.95	756.7
APR 4 SEP 9	-6.24	5.94	815.7	-6.24	5.62	782.6	-6.24	5.28	746.3	-6.24	4.92	708.6	-6.24	4.54	671.1
MAR 21 SEP 23	-6.00	5.67	741.1	-6.00	5.31	701.0	-6.00	4.93	659.4	-6.00	4.53	618.0	-6.00	4.12	578.3
MAR 7 OCT 8	-5.76	5.39	662.0	-5.76	5.00	616.0	-5.76	4.58	570.2	-5.76	4.14	526.2	-5.76	3.70	485.4
FEB 20 OCT 22	-5.54	5.13	584.3	-5.54	4.70	533.8	-5.54	4.24	485.2	-5.54	3.77	439.8	-5.54	3.30	398.8
FEB 7 NOV 5	-5.33	4.89	513.2	-5.33	4.42	459.8	-5.33	3.93	409.6	-5.33	3.43	363.9	-5.33	2.92	323.7
JAN 23 NOV 19	-5.16	4.68	455.2	-5.16	4.18	400.1	-5.16	3.66	349.3	-5.16	3.13	304.1	-5.16	2.60	265.1
JAN 10 DEC 3	-5.03	4.53	414.1	-5.03	4.01	358.3	-5.03	3.46	307.5	-5.03	2.91	262.9	-5.03	2.35	225.1
DEC 22	-4.95	4.44	390.0	-4.95	3.90	333.9	-4.95	3.34	283.4	-4.95	2.77	239.4	-4.95	2.20	202.4
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	265.436		.5050	252.732		.4808	239.459		.4556	226.176		.4303	213.375		.4060

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	49.7		34.2	51.1		40.2	52.0		45.9	52.7		51.2	53.0		56.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	5.77	928.6	-7.05	5.49	900.2	-7.05	5.20	871.7	-7.05	4.90	844.0	-7.05	4.60	817.5
JUN 1 JUL 12	-6.97	5.61	903.6	-6.97	5.32	874.4	-6.97	5.01	845.4	-6.97	4.71	817.5	-6.97	4.41	791.0
MAY 18 JUL 27	-6.84	5.35	860.6	-6.84	5.04	830.2	-6.84	4.72	800.6	-6.84	4.41	772.4	-6.84	4.10	746.0
MAY 3 AUG 10	-6.67	5.00	799.3	-6.67	4.67	767.6	-6.67	4.34	737.3	-6.67	4.01	709.0	-6.67	3.70	682.8
APR 19 AUG 25	-6.46	4.59	722.4	-6.46	4.24	689.6	-6.46	3.89	658.9	-6.46	3.56	630.9	-6.46	3.24	605.3
APR 4 SEP 9	-6.24	4.16	635.2	-6.24	3.79	601.7	-6.24	3.42	571.1	-6.24	3.08	543.8	-6.24	2.75	519.3
MAR 21 SEP 23	-6.00	3.72	541.5	-6.00	3.32	508.1	-6.00	2.94	478.3	-6.00	2.58	452.3	-6.00	2.25	429.4
MAR 7 OCT 8	-5.76	3.27	448.5	-5.76	2.85	416.0	-5.76	2.46	387.7	-5.76	2.09	363.5	-5.76	1.75	342.6
FEB 20 OCT 22	-5.54	2.84	362.9	-5.54	2.40	331.9	-5.54	1.99	305.6	-5.54	1.61	283.6	-5.54	1.26	264.9
FEB 7 NOV 5	-5.33	2.44	289.2	-5.33	1.97	260.2	-5.33	1.54	236.3	-5.33	1.15	216.5	-5.33	.80	200.3
JAN 23 NOV 19	-5.16	2.09	232.3	-5.16	1.60	205.4	-5.16	1.16	183.6	-5.16	.76	166.1	-5.16	.40	151.9
JAN 10 DEC 3	-5.03	1.82	193.9	-5.03	1.32	168.7	-5.03	.86	148.6	-5.03	.46	132.8	-5.03	.09	120.2
DEC 22	-4.95	1.66	172.2	-4.95	1.15	148.1	-4.95	.68	129.2	-4.95	.27	114.4	-4.95	-.10	102.7
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	201.413		.3832	190.477		.3624	180.667		.3437	171.972		.3272	164.253		.3125

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 32 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 27.9		ALPHA 4.6	THETA 23.7		ALPHA 8.7	THETA 19.6		ALPHA 12.5	THETA 15.6		ALPHA 15.8	THETA 11.9		ALPHA 18.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	6.58	998.2	-7.05	6.15	981.4	-7.05	5.76	960.5	-7.05	5.41	936.4	-7.05	5.09	910.0
JUN 1 JUL 12	-6.97	6.52	989.7	-6.97	6.10	976.0	-6.97	5.72	958.0	-6.97	5.38	936.4	-6.97	5.07	912.4
MAY 18 JUL 27	-6.84	6.41	973.8	-6.84	6.01	965.3	-6.84	5.65	952.2	-6.84	5.32	935.1	-6.84	5.03	915.0
MAY 3 AUG 10	-6.67	6.26	948.6	-6.67	5.89	947.4	-6.67	5.55	940.9	-6.67	5.24	930.0	-6.67	4.97	915.4
APR 19 AUG 25	-6.46	6.09	912.7	-6.46	5.74	920.0	-6.46	5.43	921.6	-6.46	5.15	918.1	-6.46	4.90	910.2
APR 4 SEP 9	-6.24	5.89	866.2	-6.24	5.58	882.7	-6.24	5.30	893.0	-6.24	5.05	897.5	-6.24	4.82	897.0
MAR 21 SEP 23	-6.00	5.70	809.4	-6.00	5.42	834.9	-6.00	5.17	853.9	-6.00	4.95	866.5	-6.00	4.74	873.4
MAR 7 OCT 8	-5.76	5.50	746.2	-5.76	5.25	779.9	-5.76	5.04	806.8	-5.76	4.84	827.0	-5.76	4.66	840.9
FEB 20 OCT 22	-5.54	5.30	681.3	-5.54	5.10	721.9	-5.54	4.91	755.5	-5.54	4.74	782.1	-5.54	4.59	802.1
FEB 7 NOV 5	-5.33	5.13	619.7	-5.33	4.95	665.6	-5.33	4.79	704.4	-5.33	4.65	736.2	-5.33	4.52	761.1
JAN 23 NOV 19	-5.16	4.98	568.0	-5.16	4.83	617.4	-5.16	4.69	660.0	-5.16	4.57	695.5	-5.16	4.46	724.0
JAN 10 DEC 3	-5.03	4.87	530.5	-5.03	4.74	582.2	-5.03	4.62	627.0	-5.03	4.51	664.8	-5.03	4.42	695.6
DEC 22	-4.95	4.81	508.2	-4.95	4.69	561.0	-4.95	4.58	607.1	-4.95	4.48	646.1	-4.95	4.39	678.1
	YEAR 286.775		R.I. .5456	YEAR 294.532		R.I. .5604	YEAR 300.109		R.I. .5710	YEAR 303.595		R.I. .5776	YEAR 305.212		R.I. .5807

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 8.4		ALPHA 21.6	THETA 5.2		ALPHA 24.0	THETA 2.2		ALPHA 26.2	THETA -0.4		ALPHA 28.2	THETA -2.8		ALPHA 30.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	4.81	882.4	-7.05	4.55	854.5	-7.05	4.32	827.0	-7.05	4.11	800.5	-7.05	3.92	775.2
JUN 1 JUL 12	-6.97	4.79	886.8	-6.97	4.54	860.7	-6.97	4.31	834.7	-6.97	4.11	809.6	-6.97	3.92	785.3
MAY 18 JUL 27	-6.84	4.76	892.9	-6.84	4.52	869.8	-6.84	4.30	846.5	-6.84	4.11	823.5	-6.84	3.93	801.2
MAY 3 AUG 10	-6.67	4.72	898.3	-6.67	4.49	879.4	-6.67	4.29	859.8	-6.67	4.11	840.0	-6.67	3.94	820.5
APR 19 AUG 25	-6.46	4.67	899.0	-6.46	4.46	885.4	-6.46	4.28	870.4	-6.46	4.11	854.6	-6.46	3.96	838.4
APR 4 SEP 9	-6.24	4.62	892.4	-6.24	4.43	884.6	-6.24	4.27	874.7	-6.24	4.12	863.3	-6.24	3.98	851.1
MAR 21 SEP 23	-6.00	4.56	875.5	-6.00	4.40	873.8	-6.00	4.25	869.2	-6.00	4.12	862.5	-6.00	4.00	854.5
MAR 7 OCT 8	-5.76	4.51	849.4	-5.76	4.36	853.5	-5.76	4.24	854.1	-5.76	4.12	852.0	-5.76	4.02	848.0
FEB 20 OCT 22	-5.54	4.45	816.3	-5.54	4.33	825.5	-5.54	4.22	830.8	-5.54	4.12	832.9	-5.54	4.03	832.7
FEB 7 NOV 5	-5.33	4.40	779.9	-5.33	4.30	795.4	-5.33	4.21	802.5	-5.33	4.13	808.2	-5.33	4.05	811.2
JAN 23 NOV 19	-5.16	4.36	746.2	-5.16	4.28	762.9	-5.16	4.20	775.0	-5.16	4.13	783.4	-5.16	4.06	788.9
JAN 10 DEC 3	-5.03	4.33	720.0	-5.03	4.26	738.9	-5.03	4.19	753.0	-5.03	4.13	763.2	-5.03	4.07	770.3
DEC 22	-4.95	4.32	703.8	-4.95	4.25	723.8	-4.95	4.19	738.9	-4.95	4.13	750.2	-4.95	4.08	758.3
	YEAR 305.268		R.I. .5808	YEAR 304.095		R.I. .5786	YEAR 302.013		R.I. .5746	YEAR 299.300		R.I. .5694	YEAR 296.156		R.I. .5635

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 32 N
ASPECT ENE - WNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	34.0		6.4	35.7		12.9	36.9		19.4	37.8		25.7	38.3		31.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	6.71	1011.9	-7.05	6.35	1006.3	-7.05	5.98	994.7	-7.05	5.60	978.6	-7.05	5.22	959.3
JUN 1 JUL 12	-6.97	6.63	998.5	-6.97	6.26	991.5	-6.97	5.88	978.9	-6.97	5.50	962.1	-6.97	5.12	942.4
MAY 18 JUL 27	-6.84	6.49	974.4	-6.84	6.11	965.2	-6.84	5.73	951.0	-6.84	5.34	933.0	-6.84	4.95	912.7
MAY 3 AUG 10	-6.67	6.30	937.9	-6.67	5.91	925.8	-6.67	5.51	909.4	-6.67	5.12	890.0	-6.67	4.73	868.9
APR 19 AUG 25	-6.46	6.07	888.6	-6.46	5.67	873.1	-6.46	5.26	854.3	-6.46	4.86	833.4	-6.46	4.47	811.5
APR 4 SEP 9	-6.24	5.83	828.2	-6.24	5.41	809.2	-6.24	4.99	788.0	-6.24	4.58	765.7	-6.24	4.18	743.3
MAR 21 SEP 23	-6.00	5.57	757.7	-6.00	5.14	735.5	-6.00	4.71	712.3	-6.00	4.28	689.0	-6.00	3.88	666.3
MAR 7 OCT 8	-5.76	5.32	682.3	-5.76	4.87	657.5	-5.76	4.42	632.7	-5.76	3.99	608.8	-5.76	3.59	586.3
FEB 20 OCT 22	-5.54	5.08	607.5	-5.54	4.61	580.7	-5.54	4.15	555.0	-5.54	3.71	531.0	-5.54	3.30	509.1
FEB 7 NOV 5	-5.33	4.85	538.6	-5.33	4.37	510.5	-5.33	3.90	484.4	-5.33	3.45	460.7	-5.33	3.04	439.5
JAN 23 NOV 19	-5.16	4.66	481.9	-5.16	4.17	453.2	-5.16	3.69	427.0	-5.16	3.23	403.8	-5.16	2.81	383.5
JAN 10 DEC 3	-5.03	4.52	441.6	-5.03	4.02	412.6	-5.03	3.53	386.6	-5.03	3.07	363.8	-5.03	2.65	344.2
DEC 22	-4.95	4.44	417.9	-4.95	3.93	388.8	-4.95	3.44	363.0	-4.95	2.97	340.6	-4.95	2.55	321.4
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	270.620		.5149	263.460		.5013	255.836		.4867	248.064		.4720	240.416		.4574

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	38.4		37.4	38.3		42.5	38.1		47.2	37.7		51.3	37.2		55.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	4.85	938.5	-7.05	4.51	916.9	-7.05	4.18	895.6	-7.05	3.89	875.1	-7.05	3.61	855.5
JUN 1 JUL 12	-6.97	4.75	921.3	-6.97	4.41	899.8	-6.97	4.08	878.5	-6.97	3.79	858.2	-6.97	3.52	838.8
MAY 18 JUL 27	-6.84	4.59	891.3	-6.84	4.24	869.7	-6.84	3.92	848.6	-6.84	3.63	828.5	-6.84	3.36	809.5
MAY 3 AUG 10	-6.67	4.36	847.1	-6.67	4.02	825.6	-6.67	3.70	804.9	-6.67	3.41	785.3	-6.67	3.14	766.8
APR 19 AUG 25	-6.46	4.10	789.6	-6.46	3.75	768.3	-6.46	3.44	748.1	-6.46	3.15	729.2	-6.46	2.89	711.6
APR 4 SEP 9	-6.24	3.81	721.4	-6.24	3.47	700.6	-6.24	3.15	681.2	-6.24	2.87	663.3	-6.24	2.61	646.8
MAR 21 SEP 23	-6.00	3.51	644.9	-6.00	3.17	624.9	-6.00	2.86	606.6	-6.00	2.58	589.9	-6.00	2.33	574.6
MAR 7 OCT 8	-5.76	3.21	565.6	-5.76	2.87	546.7	-5.76	2.56	529.7	-5.76	2.29	514.3	-5.76	2.04	500.5
FEB 20 OCT 22	-5.54	2.92	489.3	-5.54	2.58	471.6	-5.54	2.28	456.0	-5.54	2.01	442.1	-5.54	1.77	429.7
FEB 7 NOV 5	-5.33	2.66	420.9	-5.33	2.32	404.5	-5.33	2.02	390.2	-5.33	1.75	377.8	-5.33	1.51	366.7
JAN 23 NOV 19	-5.16	2.43	365.9	-5.16	2.09	350.7	-5.16	1.79	337.6	-5.16	1.53	326.3	-5.16	1.30	316.5
JAN 10 DEC 3	-5.03	2.27	327.5	-5.03	1.93	313.2	-5.03	1.63	301.0	-5.03	1.37	290.6	-5.03	1.14	281.5
DEC 22	-4.95	2.17	305.2	-4.95	1.83	291.5	-4.95	1.53	279.8	-4.95	1.27	269.9	-4.95	1.05	261.4
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	233.091		.4435	226.198		.4304	219.811		.4182	213.952		.4071	208.561		.3968

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 32 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 29.7		ALPHA 6.1	THETA 27.1		ALPHA 11.8	THETA 24.5		ALPHA 17.0	THETA 21.8		ALPHA 21.7	THETA 19.2		ALPHA 25.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	6.55	1003.0	-7.05	6.07	991.6	-7.05	5.63	976.7	-7.05	5.22	959.1	-7.05	4.85	939.4
JUN 1 JUL 12	-6.97	6.48	993.0	-6.97	6.01	983.4	-6.97	5.57	970.3	-6.97	5.17	954.2	-6.97	4.81	936.1
MAY 18 JUL 27	-6.84	6.36	974.7	-6.84	5.91	968.1	-6.84	5.48	957.9	-6.84	5.09	944.6	-6.84	4.74	928.9
MAY 3 AUG 10	-6.67	6.20	946.2	-6.67	5.76	943.8	-6.67	5.36	937.6	-6.67	4.98	928.0	-6.67	4.64	915.8
APR 19 AUG 25	-6.46	6.02	906.2	-6.46	5.59	908.8	-6.46	5.21	907.4	-6.46	4.85	902.4	-6.46	4.53	894.4
APR 4 SEP 9	-6.24	5.81	855.6	-6.24	5.41	863.4	-6.24	5.04	867.2	-6.24	4.70	867.1	-6.24	4.40	863.6
MAR 21 SEP 23	-6.00	5.59	794.6	-6.00	5.22	807.7	-6.00	4.87	816.5	-6.00	4.55	821.3	-6.00	4.27	822.5
MAR 7 OCT 8	-5.76	5.38	727.7	-5.76	5.02	745.5	-5.76	4.70	759.0	-5.76	4.40	768.3	-5.76	4.14	773.7
FEB 20 OCT 22	-5.54	5.17	659.8	-5.54	4.84	681.4	-5.54	4.53	698.9	-5.54	4.26	712.1	-5.54	4.01	721.2
FEB 7 NOV 5	-5.33	4.99	595.9	-5.33	4.67	620.5	-5.33	4.38	641.1	-5.33	4.13	657.3	-5.33	3.90	669.4
JAN 23 NOV 19	-5.16	4.83	542.6	-5.16	4.53	569.3	-5.16	4.26	591.9	-5.16	4.02	610.3	-5.16	3.80	624.5
JAN 10 DEC 3	-5.03	4.71	504.2	-5.03	4.42	532.1	-5.03	4.16	556.1	-5.03	3.93	575.8	-5.03	3.73	591.4
DEC 22	-4.95	4.64	481.4	-4.95	4.36	510.0	-4.95	4.11	534.6	-4.95	3.89	555.1	-4.95	3.69	571.3
	YEAR 282.158		R.I. .5368	YEAR 285.997		R.I. .5441	YEAR 288.401		R.I. .5487	YEAR 289.428		R.I. .5507	YEAR 289.229		R.I. .5503

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 16.7		ALPHA 29.8	THETA 14.4		ALPHA 33.2	THETA 12.2		ALPHA 36.2	THETA 10.2		ALPHA 38.9	THETA 8.4		ALPHA 41.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	4.52	918.6	-7.05	4.22	897.4	-7.05	3.95	876.3	-7.05	3.71	855.7	-7.05	3.49	835.9
JUN 1 JUL 12	-6.97	4.48	916.6	-6.97	4.18	896.5	-6.97	3.92	876.4	-6.97	3.68	856.7	-6.97	3.47	837.7
MAY 18 JUL 27	-6.84	4.42	911.7	-6.84	4.13	893.6	-6.84	3.88	875.2	-6.84	3.65	857.1	-6.84	3.44	839.3
MAY 3 AUG 10	-6.67	4.34	901.7	-6.67	4.06	886.4	-6.67	3.82	870.4	-6.67	3.60	854.4	-6.67	3.40	838.6
APR 19 AUG 25	-6.46	4.24	884.0	-6.46	3.98	872.1	-6.46	3.75	859.1	-6.46	3.54	845.8	-6.46	3.35	832.2
APR 4 SEP 9	-6.24	4.13	857.4	-6.24	3.89	849.2	-6.24	3.67	839.6	-6.24	3.47	829.1	-6.24	3.30	818.2
MAR 21 SEP 23	-6.00	4.02	820.5	-6.00	3.79	816.1	-6.00	3.59	810.0	-6.00	3.41	802.6	-6.00	3.25	794.4
MAR 7 OCT 8	-5.76	3.90	775.8	-5.76	3.69	775.0	-5.76	3.51	772.2	-5.76	3.34	767.8	-5.76	3.19	762.3
FEB 20 OCT 22	-5.54	3.80	726.7	-5.54	3.60	729.2	-5.54	3.43	729.3	-5.54	3.27	727.7	-5.54	3.14	724.6
FEB 7 NOV 5	-5.33	3.70	677.7	-5.33	3.52	682.8	-5.33	3.36	685.4	-5.33	3.22	686.0	-5.33	3.09	685.0
JAN 23 NOV 19	-5.16	3.61	634.9	-5.16	3.45	642.0	-5.16	3.30	646.4	-5.16	3.17	648.7	-5.16	3.05	649.3
JAN 10 DEC 3	-5.03	3.55	603.1	-5.03	3.39	611.5	-5.03	3.25	617.1	-5.03	3.13	620.5	-5.03	3.02	622.1
DEC 22	-4.95	3.52	583.8	-4.95	3.36	592.9	-4.95	3.23	599.1	-4.95	3.11	603.1	-4.95	3.00	605.4
	YEAR 288.018		R.I. .5480	YEAR 286.023		R.I. .5442	YEAR 283.468		R.I. .5393	YEAR 280.549		R.I. .5338	YEAR 277.393		R.I. .5278

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 32 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 31.8		ALPHA 6.7	THETA 31.3		ALPHA 13.3	THETA 30.5		ALPHA 19.5	THETA 29.5		ALPHA 25.3	THETA 28.3		ALPHA 30.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	6.59	1007.7	-7.05	6.14	1000.1	-7.05	5.69	988.4	-7.05	5.27	973.5	-7.05	4.87	956.5
JUN 1 JUL 12	-6.97	6.52	996.0	-6.97	6.06	988.7	-6.97	5.62	977.4	-6.97	5.20	963.0	-6.97	4.80	946.6
MAY 18 JUL 27	-6.84	6.39	974.8	-6.84	5.94	968.0	-6.84	5.50	957.4	-6.84	5.08	943.9	-6.84	4.69	928.4
MAY 3 AUG 10	-6.67	6.22	942.4	-6.67	5.77	936.2	-6.67	5.33	926.6	-6.67	4.92	914.3	-6.67	4.54	900.1
APR 19 AUG 25	-6.46	6.01	897.8	-6.46	5.56	892.4	-6.46	5.14	884.1	-6.46	4.73	873.3	-6.46	4.36	860.8
APR 4 SEP 9	-6.24	5.79	842.3	-6.24	5.34	837.8	-6.24	4.92	830.8	-6.24	4.53	821.8	-6.24	4.17	811.1
MAR 21 SEP 23	-6.00	5.55	776.6	-6.00	5.11	773.1	-6.00	4.70	767.6	-6.00	4.32	760.3	-6.00	3.96	751.6
MAR 7 OCT 8	-5.76	5.32	705.4	-5.76	4.89	702.9	-5.76	4.48	698.8	-5.76	4.10	693.2	-5.76	3.76	686.5
FEB 20 OCT 22	-5.54	5.09	634.0	-5.54	4.67	632.4	-5.54	4.27	629.6	-5.54	3.90	625.6	-5.54	3.57	620.6
FEB 7 NOV 5	-5.33	4.89	567.6	-5.33	4.46	566.7	-5.33	4.07	564.9	-5.33	3.71	562.3	-5.33	3.39	558.8
JAN 23 NOV 19	-5.16	4.71	512.5	-5.16	4.29	512.2	-5.16	3.91	511.3	-5.16	3.55	509.7	-5.16	3.24	507.4
JAN 10 DEC 3	-5.03	4.58	473.1	-5.03	4.17	473.2	-5.03	3.78	472.8	-5.03	3.44	471.9	-5.03	3.13	470.4
DEC 22	-4.95	4.51	449.9	-4.95	4.09	450.1	-4.95	3.71	450.1	-4.95	3.37	449.6	-4.95	3.06	448.5
	YEAR 276.506		R.I. .5261	YEAR 275.178		R.I. .5236	YEAR 273.065		R.I. .5195	YEAR 270.291		R.I. .5143	YEAR 267.007		R.I. .5080

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 27.0		ALPHA 35.3	THETA 25.7		ALPHA 39.5	THETA 24.4		ALPHA 43.3	THETA 23.2		ALPHA 46.7	THETA 22.0		ALPHA 49.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.05	4.50	938.3	-7.05	4.17	919.6	-7.05	3.87	900.9	-7.05	3.60	882.7	-7.05	3.36	865.2
JUN 1 JUL 12	-6.97	4.44	928.9	-6.97	4.11	910.7	-6.97	3.82	892.6	-6.97	3.55	874.9	-6.97	3.31	857.8
MAY 18 JUL 27	-6.84	4.34	911.7	-6.84	4.01	894.4	-6.84	3.72	877.2	-6.84	3.46	860.3	-6.84	3.23	844.0
MAY 3 AUG 10	-6.67	4.19	884.8	-6.67	3.88	868.9	-6.67	3.60	852.9	-6.67	3.34	837.3	-6.67	3.12	822.1
APR 19 AUG 25	-6.46	4.02	847.1	-6.46	3.72	832.9	-6.46	3.45	818.6	-6.46	3.20	804.4	-6.46	2.98	790.7
APR 4 SEP 9	-6.24	3.84	799.4	-6.24	3.55	787.1	-6.24	3.28	774.6	-6.24	3.05	762.2	-6.24	2.84	750.0
MAR 21 SEP 23	-6.00	3.65	741.9	-6.00	3.36	731.6	-6.00	3.11	721.1	-6.00	2.89	710.5	-6.00	2.69	700.1
MAR 7 OCT 8	-5.76	3.46	678.8	-5.76	3.18	670.6	-5.76	2.94	661.9	-5.76	2.73	653.2	-5.76	2.53	644.6
FEB 20 OCT 22	-5.54	3.27	614.8	-5.54	3.01	608.4	-5.54	2.78	601.5	-5.54	2.57	594.5	-5.54	2.39	587.5
FEB 7 NOV 5	-5.33	3.10	554.6	-5.33	2.85	549.7	-5.33	2.63	544.4	-5.33	2.43	538.9	-5.33	2.26	533.2
JAN 23 NOV 19	-5.16	2.96	504.3	-5.16	2.71	500.7	-5.16	2.50	496.6	-5.16	2.31	492.2	-5.16	2.14	487.5
JAN 10 DEC 3	-5.03	2.86	468.1	-5.03	2.62	465.3	-5.03	2.41	462.0	-5.03	2.22	458.3	-5.03	2.06	454.5
DEC 22	-4.95	2.79	446.7	-4.95	2.56	444.3	-4.95	2.35	441.4	-4.95	2.17	438.2	-4.95	2.01	434.8
	YEAR 263.370		R.I. .5011	YEAR 259.518		R.I. .4938	YEAR 255.581		R.I. .4863	YEAR 251.664		R.I. .4788	YEAR 247.804		R.I. .4715

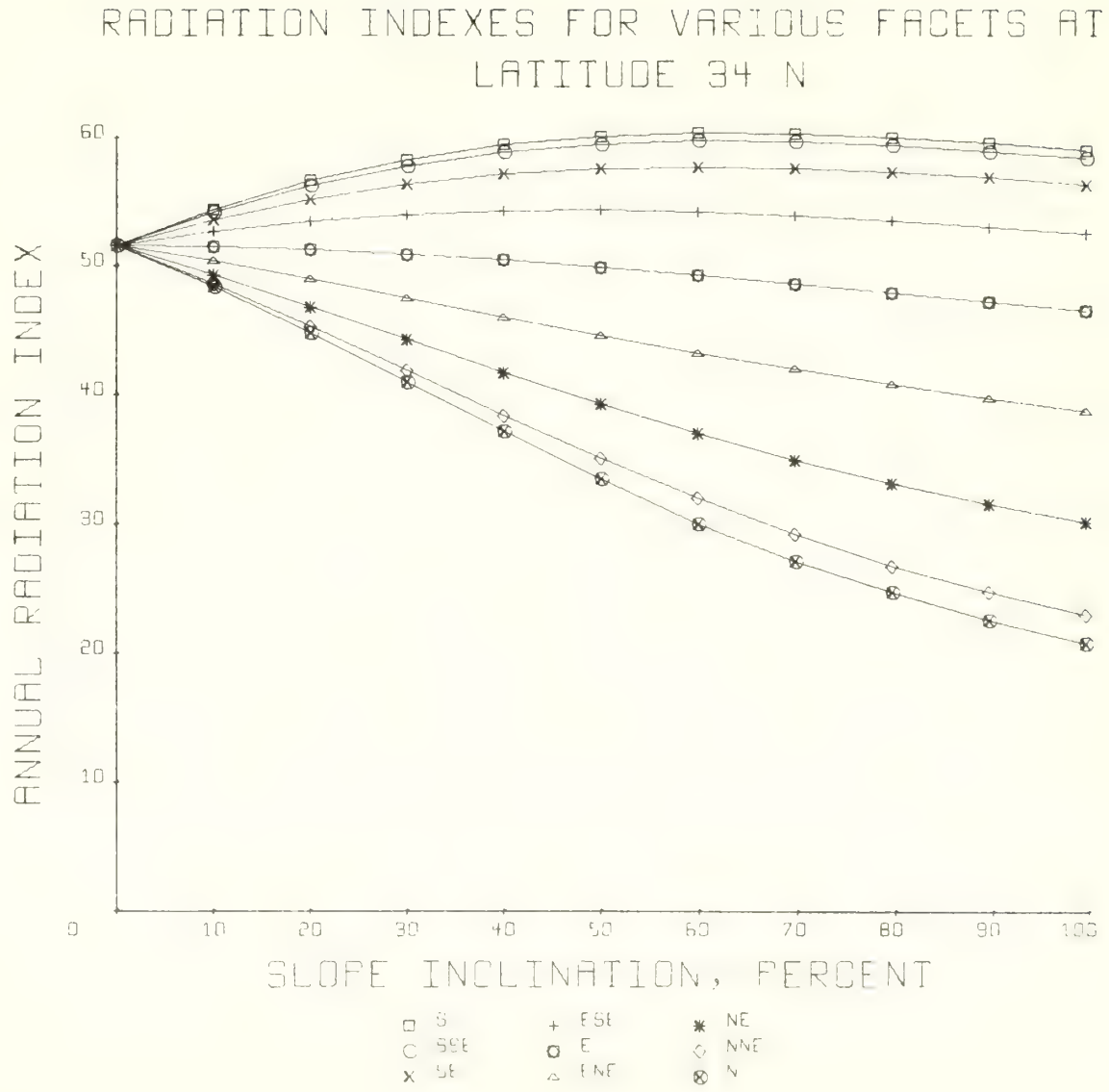
NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 34 N

		SR	SS	LY
JUN 22		-7.14	7.14	1014.8
JUN 1	JUL 12	-7.05	7.05	1001.4
MAY 18	JUL 27	-6.91	6.91	977.2
MAY 3	AUG 10	-6.72	6.72	940.8
APR 19	AUG 25	-6.50	6.50	891.4
APR 4	SEP 9	-6.25	6.25	830.9
MAR 21	SEP 23	-6.00	6.00	760.3
MAR 7	OCT 8	-5.75	5.75	684.8
FEB 20	OCT 22	-5.50	5.50	609.8
FEB 7	NOV 5	-5.28	5.28	540.7
JAN 23	NOV 19	-5.09	5.09	483.9
JAN 10	DEC 3	-4.95	4.95	443.4
DEC 22		-4.86	4.86	419.7

YEAR	R.I.
271.525	.5166



LATITUDE 34 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 39.7		ALPHA 0.0	THETA 45.3		ALPHA 0.0	THETA 50.7		ALPHA 0.0	THETA 55.8		ALPHA 0.0	THETA 60.6		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	7.14	1021.0	-7.14	7.14	1017.3	-7.14	7.14	1004.5	-7.14	7.14	984.2	-7.14	7.14	958.2
JUN 1 JUL 12	-7.05	7.05	1002.9	-7.05	7.05	994.7	-7.05	7.05	977.9	-7.05	7.05	954.0	-7.05	7.05	924.9
MAY 18 JUL 27	-6.91	6.91	971.0	-6.91	6.91	955.5	-6.91	6.91	931.9	-6.91	6.91	902.1	-6.91	6.91	867.7
MAY 3 AUG 10	-6.72	6.72	923.8	-6.72	6.72	898.4	-6.72	6.72	865.8	-6.72	6.72	827.8	-6.72	6.72	786.5
APR 19 AUG 25	-6.50	6.50	862.1	-6.50	6.50	825.0	-6.50	6.50	781.9	-6.50	6.50	734.7	-6.50	6.50	685.3
APR 4 SEP 9	-6.25	6.25	788.5	-6.25	6.25	739.4	-6.25	6.25	685.5	-6.25	6.25	628.9	-6.25	6.25	571.4
MAR 21 SEP 23	-6.00	6.00	705.4	-6.00	6.00	644.9	-6.00	6.00	580.9	-6.00	6.00	515.5	-6.00	6.00	450.7
MAR 7 OCT 8	-5.69	5.69	619.0	-5.62	5.62	548.9	-5.54	5.54	476.7	-5.44	5.44	404.7	-5.33	5.33	334.9
FEB 20 OCT 22	-5.39	5.39	535.6	-5.25	5.25	458.5	-5.09	5.09	381.1	-4.90	4.90	305.8	-4.67	4.67	234.7
FEB 7 NOV 5	-5.11	5.11	460.5	-4.91	4.91	379.1	-4.67	4.67	299.4	-4.38	4.38	223.7	-4.03	4.03	154.6
JAN 23 NOV 19	-4.87	4.87	400.1	-4.61	4.61	316.6	-4.31	4.31	236.6	-3.93	3.93	162.7	-3.44	3.44	97.8
JAN 10 DEC 3	-4.69	4.69	357.8	-4.40	4.40	273.7	-4.03	4.03	194.4	-3.57	3.57	123.1	-2.96	2.96	62.8
DEC 22	-4.59	4.59	333.2	-4.26	4.26	249.1	-3.86	3.86	170.8	-3.35	3.35	101.4	-2.64	2.64	44.8
	YEAR 254.414		R.I. .4840	YEAR 235.517		R.I. .4481	YEAR 215.630		R.I. .4103	YEAR 195.546		R.I. .3720	YEAR 176.078		R.I. .3350

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 65.0		ALPHA 0.0	THETA 69.0		ALPHA 0.0	THETA 72.7		ALPHA 0.0	THETA 76.0		ALPHA 0.0	THETA 79.0		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	7.14	928.3	-7.14	7.14	896.1	-7.14	7.14	863.0	-7.14	7.14	830.0	-7.14	7.14	797.5
JUN 1 JUL 12	-7.05	7.05	892.3	-7.05	7.05	857.8	-7.05	7.05	822.7	-7.05	7.05	788.1	-7.05	7.05	754.3
MAY 18 JUL 27	-6.91	6.91	830.6	-6.91	6.91	792.3	-6.91	6.91	754.1	-6.91	6.91	716.9	-6.91	6.91	680.9
MAY 3 AUG 10	-6.72	6.72	743.4	-6.72	6.72	700.1	-6.72	6.72	657.8	-6.72	6.72	617.1	-6.72	6.72	578.3
APR 19 AUG 25	-6.50	6.50	635.6	-6.50	6.50	586.6	-6.50	6.50	539.6	-6.50	6.50	495.2	-6.50	6.50	453.3
APR 4 SEP 9	-6.25	6.25	514.9	-6.25	6.25	460.4	-6.25	6.25	408.8	-6.25	6.25	360.8	-6.25	6.25	316.0
MAR 21 SEP 23	-6.00	6.00	388.1	-6.00	6.00	328.7	-6.00	6.00	273.2	-6.00	6.00	222.1	-6.00	6.00	175.0
MAR 7 OCT 8	-5.19	5.19	268.9	-5.01	5.01	207.6	-4.77	4.77	151.9	-4.45	4.45	102.2	-3.97	3.97	58.7
FEB 20 OCT 22	-4.37	4.37	169.5	-3.99	3.99	111.4	-3.46	3.46	61.9	-2.63	2.63	22.9	-.47	.47	.1
FEB 7 NOV 5	-3.56	3.56	94.1	-2.89	2.89	44.3	-1.78	1.78	8.9	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	-2.75	2.75	44.6	-1.60	1.60	7.6	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	-2.02	2.02	17.7	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-1.43	1.43	6.3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 158.061		R.I. .3007	YEAR 142.687		R.I. .2715	YEAR 129.800		R.I. .2470	YEAR 118.722		R.I. .2259	YEAR 108.931		R.I. .2073

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 34 N
ASPECT S -

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	28.3	0.0	22.7	0.0	17.3	0.0	12.2	0.0	7.4	0.0

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.90	6.90	999.8	-6.70	6.70	977.7	-6.52	6.52	949.5	-6.36	6.36	916.5	-6.22	6.22	880.2
JUN 1 JUL 12	-6.84	6.84	991.0	-6.65	6.65	973.2	-6.48	6.48	949.0	-6.33	6.33	919.6	-6.20	6.20	886.5
MAY 18 JUL 27	-6.73	6.73	974.7	-6.56	6.56	964.3	-6.42	6.42	946.8	-6.29	6.29	923.5	-6.17	6.17	895.9
MAY 3 AUG 10	-6.58	6.58	948.9	-6.45	6.45	948.7	-6.33	6.33	940.7	-6.23	6.23	926.1	-6.14	6.14	906.4
APR 19 AUG 25	-6.40	6.40	912.2	-6.31	6.31	924.3	-6.23	6.23	927.9	-6.16	6.16	924.1	-6.10	6.10	914.2
APR 4 SEP 9	-6.20	6.20	865.1	-6.16	6.16	890.4	-6.12	6.12	906.8	-6.08	6.08	915.0	-6.05	6.05	916.2
MAR 21 SEP 23	-6.00	6.00	807.6	-6.00	6.00	846.2	-6.00	6.00	875.6	-6.00	6.00	896.4	-6.00	6.00	909.4
MAR 7 OCT 8	-5.75	5.75	743.8	-5.75	5.75	794.4	-5.75	5.75	835.9	-5.75	5.75	868.5	-5.75	5.75	892.7
FEB 20 OCT 22	-5.50	5.50	678.3	-5.50	5.50	738.8	-5.50	5.50	790.4	-5.50	5.50	832.8	-5.50	5.50	866.5
FEB 7 NOV 5	-5.28	5.28	616.1	-5.28	5.28	684.1	-5.28	5.28	743.3	-5.28	5.28	793.3	-5.28	5.28	834.4
JAN 23 NOV 19	-5.09	5.09	563.9	-5.09	5.09	636.9	-5.09	5.09	701.3	-5.09	5.09	756.6	-5.09	5.09	802.9
JAN 10 DEC 3	-4.95	4.95	526.1	-4.95	4.95	602.0	-4.95	4.95	669.5	-4.95	4.95	728.1	-4.95	4.95	777.6
DEC 22	-4.86	4.86	503.6	-4.86	4.86	580.9	-4.86	4.86	650.0	-4.86	4.86	710.3	-4.86	4.86	761.5

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
286.193	.5445	298.008	.5670	306.852	.5838	312.869	.5953	316.363	.6019

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	3.0	0.0	-1.0	0.0	-4.7	0.0	-8.0	0.0	-11.0	0.0

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.09	6.09	842.4	-5.97	5.97	804.1	-5.86	5.86	766.4	-5.77	5.77	730.3	-5.68	5.68	695.7
JUN 1 JUL 12	-6.08	6.08	851.4	-5.97	5.97	815.5	-5.87	5.87	779.9	-5.78	5.78	745.4	-5.70	5.70	712.3
MAY 18 JUL 27	-6.07	6.07	865.6	-5.98	5.98	833.8	-5.89	5.89	801.9	-5.81	5.81	770.5	-5.74	5.74	740.0
MAY 3 AUG 10	-6.06	6.06	883.0	-5.98	5.98	857.4	-5.91	5.91	830.7	-5.85	5.85	803.8	-5.79	5.79	777.2
APR 19 AUG 25	-6.04	6.04	899.6	-5.99	5.99	881.8	-5.94	5.94	861.9	-5.90	5.90	841.0	-5.86	5.86	819.7
APR 4 SEP 9	-6.02	6.02	911.8	-5.99	5.99	903.0	-5.97	5.97	891.2	-5.95	5.95	877.4	-5.93	5.93	862.4
MAR 21 SEP 23	-6.00	6.00	915.8	-6.00	6.00	917.0	-6.00	6.00	914.1	-6.00	6.00	908.2	-6.00	6.00	900.2
MAR 7 OCT 8	-5.75	5.75	909.5	-5.75	5.75	920.3	-5.75	5.75	926.1	-5.75	5.75	926.1	-5.75	5.75	927.2
FEB 20 OCT 22	-5.50	5.50	892.2	-5.50	5.50	911.3	-5.50	5.50	924.6	-5.50	5.50	933.5	-5.50	5.50	938.8
FEB 7 NOV 5	-5.28	5.28	867.1	-5.28	5.28	892.8	-5.28	5.28	912.2	-5.28	5.28	926.6	-5.28	5.28	937.0
JAN 23 NOV 19	-5.09	5.09	840.7	-5.09	5.09	871.1	-5.09	5.09	894.9	-5.09	5.09	913.3	-5.09	5.09	927.3
JAN 10 DEC 3	-4.95	4.95	818.5	-4.95	4.95	851.8	-4.95	4.95	878.4	-4.95	4.95	899.4	-4.95	4.95	915.7
DEC 22	-4.86	4.86	804.0	-4.86	4.86	838.9	-4.86	4.86	867.0	-4.86	4.86	889.4	-4.86	4.86	907.1

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
317.736	.6045	317.413	.6039	315.830	.6009	313.336	.5961	310.193	.5901

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 34 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 39.3		ALPHA 2.8	THETA 44.3		ALPHA 6.0	THETA 49.1		ALPHA 9.7	THETA 53.5		ALPHA 13.8	THETA 57.4		ALPHA 18.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	7.14	1020.2	-7.14	7.14	1015.6	-7.14	7.14	1002.0	-7.14	7.14	981.0	-7.14	7.14	954.4
JUN 1 JUL 12	-7.05	7.05	1002.4	-7.05	7.05	993.7	-7.05	7.05	976.5	-7.05	7.05	952.2	-7.05	7.05	922.7
MAY 18 JUL 27	-6.91	6.91	971.1	-6.91	6.91	955.7	-6.91	6.91	932.2	-6.91	6.91	902.5	-6.91	6.91	868.2
MAY 3 AUG 10	-6.72	6.59	924.8	-6.72	6.65	900.2	-6.72	6.61	868.6	-6.72	6.55	831.5	-6.72	6.49	791.0
APR 19 AUG 25	-6.50	6.42	864.1	-6.50	6.32	829.1	-6.50	6.21	788.2	-6.50	6.09	743.3	-6.50	5.94	696.3
APR 4 SEP 9	-6.25	6.12	791.7	-6.25	5.97	746.0	-6.25	5.79	696.1	-6.25	5.59	643.7	-6.25	5.36	591.1
MAR 21 SEP 23	-6.00	5.81	709.8	-6.00	5.60	654.4	-6.00	5.36	596.4	-6.00	5.08	537.9	-6.00	4.76	480.9
MAR 7 OCT 8	-5.75	5.50	624.4	-5.75	5.23	560.9	-5.75	4.92	496.6	-5.75	4.57	433.8	-5.75	4.17	374.5
FEB 20 OCT 22	-5.50	5.21	541.8	-5.50	4.87	472.2	-5.50	4.50	403.7	-5.50	4.07	338.7	-5.50	3.59	279.1
FEB 7 NOV 5	-5.28	4.93	467.2	-5.28	4.54	395.8	-5.28	4.10	323.2	-5.28	3.60	257.6	-5.28	3.04	199.5
JAN 23 NOV 19	-5.08	4.70	407.0	-5.07	4.26	331.6	-5.05	3.76	260.4	-5.04	3.19	195.9	-5.02	2.54	140.0
JAN 10 DEC 3	-4.91	4.53	364.8	-4.86	4.05	288.6	-4.80	3.51	217.9	-4.72	2.88	154.9	-4.63	2.15	101.6
DEC 22	-4.80	4.42	340.3	-4.73	3.92	264.0	-4.64	3.35	193.8	-4.52	2.68	132.2	-4.38	1.90	81.0
	YEAR 255.749		R.I. .4866	YEAR 238.414		R.I. .4536	YEAR 220.284		R.I. .4191	YEAR 202.101		R.I. .3845	YEAR 184.563		R.I. .3511

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 60.9		ALPHA 23.9	THETA 63.8		ALPHA 29.8	THETA 66.2		ALPHA 36.4	THETA 68.1		ALPHA 43.4	THETA 69.6		ALPHA 50.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	7.14	923.9	-7.14	7.14	891.2	-7.14	7.14	857.6	-7.14	7.14	824.2	-7.14	7.14	791.4
JUN 1 JUL 12	-7.05	7.05	889.7	-7.05	7.05	854.9	-7.05	7.05	819.6	-7.05	7.05	784.8	-7.05	7.05	750.8
MAY 18 JUL 27	-6.91	6.91	831.2	-6.91	6.91	793.0	-6.91	6.91	754.8	-6.91	6.91	717.6	-6.91	6.91	681.7
MAY 3 AUG 10	-6.72	6.41	748.8	-6.72	6.31	706.4	-6.72	6.19	664.8	-6.72	6.04	625.1	-6.72	5.84	587.3
APR 19 AUG 25	-6.50	5.76	649.1	-6.50	5.55	602.9	-6.50	5.31	558.9	-6.50	5.02	517.9	-6.50	4.69	479.9
APR 4 SEP 9	-6.25	5.09	539.8	-6.25	4.78	491.1	-6.25	4.44	446.1	-6.25	4.05	405.4	-6.25	3.64	368.9
MAR 21 SEP 23	-6.00	4.41	427.2	-6.00	4.01	377.9	-6.00	3.57	333.7	-6.00	3.11	295.0	-6.00	2.62	261.5
MAR 7 OCT 8	-5.75	3.73	320.3	-5.75	3.24	272.1	-5.75	2.71	230.4	-5.75	2.16	195.4	-5.75	1.59	166.4
FEB 20 OCT 22	-5.50	3.06	226.2	-5.50	2.47	180.9	-5.50	1.84	143.5	-5.50	1.19	113.5	-5.50	.54	90.1
FEB 7 NOV 5	-5.28	2.41	149.6	-5.28	1.71	108.5	-5.28	.96	76.4	-5.28	.17	52.5	-5.28	-.61	35.6
JAN 23 NOV 19	-4.99	1.81	93.7	-4.95	.98	57.6	-4.91	.05	31.3	-4.83	-.95	14.1	-4.70	-2.07	4.2
JAN 10 DEC 3	-4.50	1.32	59.2	-4.31	.34	28.0	-4.00	-.85	8.2	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-4.17	.99	41.5	-3.84	-.13	14.3	-3.04	-1.81	.5	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 168.246		R.I. .3201	YEAR 153.529		R.I. .2921	YEAR 140.691		R.I. .2677	YEAR 129.846		R.I. .2470	YEAR 120.482		R.I. .2292

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 34 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 28.7		ALPHA 2.5	THETA 23.5		ALPHA 4.7	THETA 18.4		ALPHA 6.7	THETA 13.6		ALPHA 8.4	THETA 9.1		ALPHA 10.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.08	6.75	1001.1	-7.04	6.41	981.2	-7.00	6.11	955.8	-6.96	5.84	926.0	-6.93	5.60	893.2
JUN 1 JUL 12	-7.02	6.68	992.0	-6.98	6.36	976.1	-6.96	6.07	954.5	-6.93	5.81	928.1	-6.91	5.58	898.4
MAY 18 JUL 27	-6.90	6.57	975.1	-6.90	6.27	966.2	-6.89	6.00	950.9	-6.88	5.76	930.4	-6.88	5.55	906.0
MAY 3 AUG 10	-6.72	6.42	948.6	-6.72	6.15	949.2	-6.72	5.91	942.9	-6.72	5.70	930.6	-6.72	5.50	913.6
APR 19 AUG 25	-6.50	6.24	911.0	-6.50	6.01	922.8	-6.50	5.80	927.3	-6.50	5.62	925.0	-6.50	5.45	917.0
APR 4 SEP 9	-6.25	6.04	862.7	-6.25	5.85	886.7	-6.25	5.68	902.6	-6.25	5.53	911.1	-6.25	5.39	913.1
MAR 21 SEP 23	-6.00	5.83	804.1	-6.00	5.69	839.9	-6.00	5.56	867.3	-6.00	5.44	886.7	-6.00	5.33	898.8
MAR 7 OCT 8	-5.75	5.63	739.2	-5.75	5.52	785.8	-5.75	5.43	823.7	-5.75	5.35	853.2	-5.75	5.27	874.8
FEB 20 OCT 22	-5.50	5.43	672.9	-5.50	5.37	728.4	-5.50	5.31	775.2	-5.50	5.26	813.4	-5.50	5.22	843.3
FEB 7 NOV 5	-5.28	5.25	610.2	-5.28	5.22	672.4	-5.28	5.20	726.2	-5.28	5.18	771.3	-5.28	5.16	807.9
JAN 23 NOV 19	-5.09	5.09	557.6	-5.09	5.09	624.5	-5.09	5.09	683.2	-5.09	5.09	733.2	-5.09	5.09	774.7
JAN 10 DEC 3	-4.95	4.95	519.6	-4.95	4.95	589.2	-4.95	4.95	650.9	-4.95	4.95	704.0	-4.95	4.95	748.6
DEC 22	-4.86	4.86	497.0	-4.86	4.86	568.0	-4.86	4.86	631.2	-4.86	4.86	685.8	-4.86	4.86	732.1
	YEAR 285.097		R.I. .5424	YEAR 296.053		R.I. .5633	YEAR 304.259		R.I. .5789	YEAR 309.833		R.I. .5895	YEAR 313.052		R.I. .5956

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 4.9		ALPHA 11.4	THETA 1.1		ALPHA 12.7	THETA -2.1		ALPHA 13.8	THETA -5.5		ALPHA 14.9	THETA -9.4		ALPHA 15.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.90	5.38	858.9	-6.88	5.19	824.2	-6.85	5.01	790.0	-6.83	4.85	757.0	-6.81	4.70	725.5
JUN 1 JUL 12	-6.89	5.37	866.8	-6.87	5.18	834.4	-6.86	5.01	802.2	-6.84	4.86	770.9	-6.83	4.71	740.9
MAY 18 JUL 27	-6.87	5.35	879.0	-6.87	5.18	850.6	-6.87	5.02	822.0	-6.86	4.88	793.7	-6.86	4.74	766.3
MAY 3 AUG 10	-6.72	5.33	893.3	-6.72	5.17	870.8	-6.72	5.03	847.2	-6.72	4.90	823.4	-6.72	4.78	799.7
APR 19 AUG 25	-6.50	5.30	904.8	-6.50	5.17	889.5	-6.50	5.05	872.2	-6.50	4.93	853.9	-6.50	4.83	835.1
APR 4 SEP 9	-6.25	5.27	909.9	-6.25	5.16	902.5	-6.25	5.06	892.4	-6.25	4.97	880.3	-6.25	4.89	866.9
MAR 21 SEP 23	-6.00	5.24	904.7	-6.00	5.15	905.8	-6.00	5.08	903.0	-6.00	5.01	897.5	-6.00	4.94	889.9
MAR 7 OCT 8	-5.75	5.21	889.5	-5.75	5.15	898.6	-5.75	5.09	903.0	-5.75	5.04	903.9	-5.75	5.00	902.2
FEB 20 OCT 22	-5.50	5.18	865.8	-5.50	5.14	882.0	-5.50	5.11	892.9	-5.50	5.08	899.7	-5.50	5.05	903.3
FEB 7 NOV 5	-5.28	5.15	836.8	-5.28	5.13	858.9	-5.28	5.12	875.3	-5.28	5.11	887.1	-5.28	5.10	895.2
JAN 23 NOV 19	-5.09	5.09	806.3	-5.09	5.09	834.9	-5.09	5.09	855.5	-5.09	5.09	871.1	-5.09	5.09	882.8
JAN 10 DEC 3	-4.95	4.95	785.2	-4.95	4.95	814.6	-4.95	4.95	837.9	-4.95	4.95	856.0	-4.95	4.95	870.0
DEC 22	-4.86	4.86	770.2	-4.86	4.86	801.2	-4.86	4.86	826.0	-4.86	4.86	845.5	-4.86	4.86	860.7
	YEAR 314.286		R.I. .5980	YEAR 313.941		R.I. .5973	YEAR 312.402		R.I. .5944	YEAR 310.012		R.I. .5898	YEAR 307.020		R.I. .5841

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 37.9		ALPHA 5.1	THETA 41.6		ALPHA 10.7	THETA 44.8		ALPHA 15.6	THETA 47.5		ALPHA 22.9	THETA 49.7		ALPHA 29.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	6.98	1018.0	-7.14	6.80	1011.8	-7.14	6.59	997.5	-7.14	6.36	976.7	-7.14	6.10	951.2
JUN 1 JUL 12	-7.05	6.88	1001.3	-7.05	6.68	992.3	-7.05	6.46	975.5	-7.05	6.22	952.7	-7.05	5.94	925.7
MAY 18 JUL 27	-6.91	6.72	971.8	-6.91	6.50	958.0	-6.91	6.25	937.3	-6.91	5.98	911.2	-6.91	5.68	881.8
MAY 3 AUG 10	-6.72	6.50	928.0	-6.72	6.24	907.9	-6.72	5.96	881.8	-6.72	5.66	851.7	-6.72	5.33	819.2
APR 19 AUG 25	-6.50	6.23	870.2	-6.50	5.94	842.8	-6.50	5.63	810.9	-6.50	5.29	776.3	-6.50	4.93	740.8
APR 4 SEP 9	-6.25	5.95	800.8	-6.25	5.62	766.1	-6.25	5.27	728.4	-6.25	4.89	689.7	-6.25	4.49	651.5
MAR 21 SEP 23	-6.00	5.66	721.9	-6.00	5.29	680.3	-6.00	4.89	637.7	-6.00	4.48	595.6	-6.00	4.05	555.7
MAR 7 OCT 8	-5.75	5.36	639.0	-5.75	4.95	591.9	-5.75	4.52	545.4	-5.75	4.06	501.2	-5.75	3.61	460.6
FEB 20 OCT 22	-5.50	5.08	558.4	-5.50	4.63	507.2	-5.50	4.16	458.2	-5.50	3.67	413.1	-5.50	3.17	372.8
FEB 7 NOV 5	-5.28	4.82	485.2	-5.28	4.33	431.5	-5.28	3.82	381.4	-5.28	3.30	336.4	-5.28	2.77	297.3
JAN 23 NOV 19	-5.09	4.60	426.0	-5.09	4.08	370.9	-5.09	3.53	320.7	-5.09	2.98	276.5	-5.09	2.42	238.9
JAN 10 DEC 3	-4.95	4.44	384.2	-4.95	3.89	328.7	-4.95	3.32	278.8	-4.95	2.74	235.5	-4.95	2.16	199.4
DEC 22	-4.86	4.34	359.9	-4.86	3.78	304.3	-4.86	3.19	254.7	-4.86	2.59	212.2	-4.86	2.00	177.1
	YEAR 259.492		R.I. .4937	YEAR 246.386		R.I. .4688	YEAR 232.835		R.I. .4430	YEAR 219.403		R.I. .4174	YEAR 206.572		R.I. .3930

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 51.4		ALPHA 35.6	THETA 52.6		ALPHA 41.9	THETA 53.4		ALPHA 47.8	THETA 53.9		ALPHA 53.4	THETA 54.1		ALPHA 58.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	5.82	922.9	-7.14	5.52	893.4	-7.14	5.20	864.0	-7.14	4.88	835.6	-7.14	4.56	808.7
JUN 1 JUL 12	-7.05	5.64	896.3	-7.05	5.33	866.1	-7.05	5.01	836.3	-7.05	4.68	807.9	-7.05	4.36	781.0
MAY 18 JUL 27	-6.91	5.36	850.7	-6.91	5.03	819.5	-6.91	4.69	789.3	-6.91	4.36	760.7	-6.91	4.03	734.1
MAY 3 AUG 10	-6.72	4.99	786.2	-6.72	4.63	753.9	-6.72	4.28	723.2	-6.72	3.94	694.8	-6.72	3.61	668.7
APR 19 AUG 25	-6.50	4.55	705.9	-6.50	4.18	672.7	-6.50	3.82	642.0	-6.50	3.46	614.0	-6.50	3.13	588.8
APR 4 SEP 9	-6.25	4.10	615.3	-6.25	3.70	581.8	-6.25	3.32	551.6	-6.25	2.96	524.7	-6.25	2.62	500.8
MAR 21 SEP 23	-6.00	3.62	519.0	-6.00	3.21	486.0	-6.00	2.81	456.9	-6.00	2.44	431.6	-6.00	2.10	409.5
MAR 7 OCT 8	-5.75	3.15	424.3	-5.75	2.71	392.5	-5.75	2.30	365.3	-5.75	1.92	342.1	-5.75	1.58	322.3
FEB 20 OCT 22	-5.50	2.69	337.8	-5.50	2.23	308.0	-5.50	1.81	283.0	-5.50	1.42	262.3	-5.50	1.07	244.9
FEB 7 NOV 5	-5.28	2.26	264.1	-5.28	1.78	236.7	-5.28	1.34	214.3	-5.28	.94	196.1	-5.28	.59	181.2
JAN 23 NOV 19	-5.09	1.89	207.8	-5.09	1.39	182.7	-5.09	.93	162.7	-5.09	.53	146.8	-5.09	.17	134.1
JAN 10 DEC 3	-4.95	1.60	170.1	-4.95	1.09	146.9	-4.95	.62	128.8	-4.95	.21	114.7	-4.95	-.16	103.6
DEC 22	-4.86	1.43	149.0	-4.86	.90	127.0	-4.86	.42	110.0	-4.86	0.00	97.0	-4.86	-.36	87.0
	YEAR 194.683		R.I. .3704	YEAR 183.900		R.I. .3499	YEAR 174.297		R.I. .3316	YEAR 165.840		R.I. .3155	YEAR 158.377		R.I. .3013

NOTE - FOR ASPECTS WITH WEST COMPONENTS. THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 34 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 29.9		ALPHA 4.7	THETA 25.7		ALPHA 8.9	THETA 21.5		ALPHA 12.6	THETA 17.5		ALPHA 16.0	THETA 13.8		ALPHA 19.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	6.65	1004.5	-7.14	6.21	989.6	-7.14	5.82	970.6	-7.14	5.46	948.2	-7.14	5.14	923.4
JUN 1 JUL 12	-7.05	6.58	994.4	-7.05	6.15	982.7	-7.05	5.77	966.6	-7.05	5.42	946.9	-7.05	5.11	924.5
MAY 18 JUL 27	-6.91	6.46	975.8	-6.91	6.06	969.4	-6.91	5.69	958.3	-6.91	5.36	943.2	-6.91	5.06	924.8
MAY 3 AUG 10	-6.72	6.30	947.0	-6.72	5.92	947.9	-6.72	5.58	943.6	-6.72	5.27	934.7	-6.72	4.99	922.0
APR 19 AUG 25	-6.50	6.11	906.6	-6.50	5.76	916.1	-6.50	5.45	920.0	-6.50	5.17	918.6	-6.50	4.91	912.7
APR 4 SEP 9	-6.25	5.91	855.5	-6.25	5.59	874.2	-6.25	5.31	886.7	-6.25	5.05	893.4	-6.25	4.83	894.9
MAR 21 SEP 23	-6.00	5.69	794.0	-6.00	5.41	821.6	-6.00	5.16	842.8	-6.00	4.93	857.5	-6.00	4.73	866.5
MAR 7 OCT 8	-5.75	5.47	726.5	-5.75	5.23	762.2	-5.75	5.01	791.1	-5.75	4.82	813.3	-5.75	4.64	829.2
FEB 20 OCT 22	-5.50	5.27	658.1	-5.50	5.05	700.4	-5.50	4.87	735.8	-5.50	4.70	764.3	-5.50	4.55	786.1
FEB 7 NOV 5	-5.28	5.07	593.8	-5.28	4.90	641.0	-5.28	4.74	681.5	-5.28	4.60	714.8	-5.28	4.47	741.4
JAN 23 NOV 19	-5.09	4.91	540.2	-5.09	4.76	590.7	-5.09	4.63	634.6	-5.09	4.51	671.4	-5.09	4.40	701.4
JAN 10 DEC 3	-4.95	4.80	501.5	-4.95	4.66	554.1	-4.95	4.55	600.0	-4.95	4.45	639.0	-4.95	4.36	671.1
DEC 22	-4.86	4.73	478.6	-4.86	4.61	532.2	-4.86	4.50	579.2	-4.86	4.41	619.3	-4.86	4.33	652.5
	YEAR 281.931		R.I. .5364	YEAR 290.330		R.I. .5524	YEAR 296.568		R.I. .5642	YEAR 300.709		R.I. .5721	YEAR 302.956		R.I. .5764

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 10.2		ALPHA 21.7	THETA 7.0		ALPHA 24.1	THETA 4.0		ALPHA 26.3	THETA 1.3		ALPHA 28.2	THETA -1.1		ALPHA 30.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	4.85	897.1	-7.14	4.60	870.4	-7.14	4.36	843.9	-7.14	4.16	818.2	-7.14	3.97	793.5
JUN 1 JUL 12	-7.05	4.83	900.3	-7.05	4.58	875.4	-7.05	4.36	850.5	-7.05	4.15	826.2	-7.05	3.97	802.7
MAY 18 JUL 27	-6.91	4.80	904.3	-6.91	4.56	882.5	-6.91	4.34	860.4	-6.91	4.15	838.4	-6.91	3.97	816.9
MAY 3 AUG 10	-6.72	4.75	906.5	-6.72	4.52	889.2	-6.72	4.32	870.8	-6.72	4.14	852.2	-6.72	3.98	833.6
APR 19 AUG 25	-6.50	4.69	903.3	-6.50	4.48	891.4	-6.50	4.30	877.7	-6.50	4.13	863.2	-6.50	3.99	848.1
APR 4 SEP 9	-6.25	4.62	892.2	-6.25	4.44	886.1	-6.25	4.27	877.7	-6.25	4.13	867.7	-6.25	3.99	856.7
MAR 21 SEP 23	-6.00	4.55	870.5	-6.00	4.39	870.5	-6.00	4.25	867.5	-6.00	4.12	862.3	-6.00	4.00	855.5
MAR 7 OCT 8	-5.75	4.49	839.6	-5.75	4.35	845.4	-5.75	4.22	847.6	-5.75	4.11	847.0	-5.75	4.01	844.3
FEB 20 OCT 22	-5.50	4.42	802.0	-5.50	4.30	812.9	-5.50	4.20	819.7	-5.50	4.10	823.3	-5.50	4.01	824.4
FEB 7 NOV 5	-5.28	4.36	761.8	-5.28	4.26	776.8	-5.28	4.17	787.4	-5.28	4.09	794.5	-5.28	4.02	798.7
JAN 23 NOV 19	-5.09	4.31	725.0	-5.09	4.23	743.2	-5.09	4.15	756.7	-5.09	4.09	766.3	-5.09	4.03	773.0
JAN 10 DEC 3	-4.95	4.27	696.8	-4.95	4.20	717.0	-4.95	4.14	732.3	-4.95	4.08	743.8	-4.95	4.03	752.1
DEC 22	-4.86	4.25	679.4	-4.86	4.19	700.6	-4.86	4.13	717.0	-4.86	4.08	729.4	-4.86	4.03	738.6
	YEAR 303.600		R.I. .5776	YEAR 302.969		R.I. .5764	YEAR 301.376		R.I. .5734	YEAR 299.101		R.I. .5691	YEAR 296.350		R.I. .5638

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 34 N
ASPECT ENE - WNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	36.0	6.5		37.6	13.2		38.8	19.9		39.6	26.4		39.9	32.6	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	6.79	1015.3	-7.14	6.42	1008.7	-7.14	6.04	996.2	-7.14	5.64	979.3	-7.14	5.25	959.5
JUN 1 JUL 12	-7.05	6.70	1000.2	-7.05	6.33	992.3	-7.05	5.93	978.8	-7.05	5.54	961.3	-7.05	5.14	941.1
MAY 18 JUL 27	-6.91	6.55	973.3	-6.91	6.16	963.2	-6.91	5.76	948.2	-6.91	5.36	929.6	-6.91	4.96	908.8
MAY 3 AUG 10	-6.72	6.34	933.1	-6.72	5.95	920.0	-6.72	5.54	902.9	-6.72	5.13	883.0	-6.72	4.73	861.6
APR 19 AUG 25	-6.50	6.10	879.4	-6.50	5.69	863.0	-6.50	5.27	843.6	-6.50	4.85	822.3	-6.50	4.45	800.4
APR 4 SEP 9	-6.25	5.84	814.3	-6.25	5.41	794.6	-6.25	4.98	773.0	-6.25	4.55	750.6	-6.25	4.14	728.2
MAR 21 SEP 23	-6.00	5.56	739.4	-6.00	5.12	716.7	-6.00	4.67	693.2	-6.00	4.24	670.0	-6.00	3.83	647.7
MAR 7 OCT 8	-5.75	5.29	660.1	-5.75	4.83	634.9	-5.75	4.37	610.2	-5.75	3.93	586.6	-5.75	3.51	564.7
FEB 20 OCT 22	-5.50	5.03	582.3	-5.50	4.55	555.3	-5.50	4.08	529.8	-5.50	3.63	506.4	-5.50	3.21	485.2
FEB 7 NOV 5	-5.28	4.78	511.1	-5.28	4.29	483.1	-5.28	3.81	457.4	-5.28	3.35	434.5	-5.28	2.93	414.2
JAN 23 NOV 19	-5.09	4.58	453.0	-5.09	4.07	424.5	-5.09	3.58	399.0	-5.09	3.11	376.7	-5.09	2.69	357.5
JAN 10 DEC 3	-4.95	4.43	411.9	-4.95	3.91	383.3	-4.95	3.41	358.1	-4.95	2.94	336.4	-4.95	2.51	317.9
DEC 22	-4.86	4.34	387.9	-4.86	3.81	359.3	-4.86	3.31	334.3	-4.86	2.83	313.0	-4.86	2.40	295.1
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	264.932	.5041		257.620	.4901		249.946	.4755		242.216	.4608		234.685	.4465	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	40.0	38.4		39.8	43.6		39.4	48.3		38.9	52.6		38.3	56.3	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	4.87	938.2	-7.14	4.51	916.4	-7.14	4.17	895.0	-7.14	3.86	874.4	-7.14	3.58	854.9
JUN 1 JUL 12	-7.05	4.76	919.6	-7.05	4.40	897.8	-7.05	4.07	876.5	-7.05	3.76	856.2	-7.05	3.48	836.9
MAY 18 JUL 27	-6.91	4.58	887.2	-6.91	4.23	865.5	-6.91	3.89	844.4	-6.91	3.59	824.5	-6.91	3.32	805.6
MAY 3 AUG 10	-6.72	4.35	839.8	-6.72	3.99	818.3	-6.72	3.66	797.8	-6.72	3.36	778.4	-6.72	3.09	760.3
APR 19 AUG 25	-6.50	4.06	778.6	-6.50	3.71	757.5	-6.50	3.39	737.7	-6.50	3.09	719.2	-6.50	2.83	702.0
APR 4 SEP 9	-6.25	3.76	706.7	-6.25	3.41	686.4	-6.25	3.09	667.5	-6.25	2.80	650.2	-6.25	2.54	634.2
MAR 21 SEP 23	-6.00	3.44	626.8	-6.00	3.09	607.4	-6.00	2.78	589.8	-6.00	2.50	573.8	-6.00	2.24	559.3
MAR 7 OCT 8	-5.75	3.13	544.7	-5.75	2.78	526.6	-5.75	2.47	510.4	-5.75	2.19	496.0	-5.75	1.95	483.0
FEB 20 OCT 22	-5.50	2.82	466.4	-5.50	2.48	449.7	-5.50	2.17	435.0	-5.50	1.90	422.1	-5.50	1.66	410.6
FEB 7 NOV 5	-5.28	2.54	396.7	-5.28	2.20	381.4	-5.28	1.89	368.2	-5.28	1.63	356.8	-5.28	1.40	346.7
JAN 23 NOV 19	-5.09	2.30	341.1	-5.09	1.96	327.1	-5.09	1.66	315.1	-5.09	1.40	304.9	-5.09	1.17	296.0
JAN 10 DEC 3	-4.95	2.12	302.4	-4.95	1.78	289.4	-4.95	1.49	278.4	-4.95	1.23	269.0	-4.95	1.01	261.0
DEC 22	-4.86	2.02	280.2	-4.86	1.68	267.7	-4.86	1.38	257.2	-4.86	1.13	248.4	-4.86	.90	240.8
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	227.531	.4329		220.842	.4202		214.677	.4084		209.043	.3977		203.875	.3879	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 34 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	31.7		6.2	29.1		12.0	26.4		17.2	23.7		22.0	21.0		26.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	6.62	1008.4	-7.14	6.13	998.1	-7.14	5.68	984.4	-7.14	5.27	967.8	-7.14	4.89	949.2
JUN 1 JUL 12	-7.05	6.55	996.8	-7.05	6.07	988.4	-7.05	5.62	976.4	-7.05	5.21	961.5	-7.05	4.84	944.4
MAY 18 JUL 27	-6.91	6.42	975.8	-6.91	5.95	970.5	-6.91	5.52	961.5	-6.91	5.12	949.4	-6.91	4.76	934.9
MAY 3 AUG 10	-6.72	6.25	943.6	-6.72	5.80	942.5	-6.72	5.38	937.6	-6.72	5.00	929.5	-6.72	4.66	918.5
APR 19 AUG 25	-6.50	6.04	899.2	-6.50	5.61	903.1	-6.50	5.22	903.2	-6.50	4.86	899.6	-6.50	4.53	893.0
APR 4 SEP 9	-6.25	5.82	843.9	-6.25	5.41	853.1	-6.25	5.04	858.4	-6.25	4.70	859.8	-6.25	4.39	857.8
MAR 21 SEP 23	-6.00	5.59	778.4	-6.00	5.20	792.8	-6.00	4.85	803.1	-6.00	4.53	809.4	-6.00	4.25	812.0
MAR 7 OCT 6	-5.75	5.35	707.3	-5.75	4.99	726.3	-5.75	4.66	741.3	-5.75	4.37	752.1	-5.75	4.10	756.9
FEB 20 OCT 22	-5.50	5.13	636.0	-5.50	4.79	658.8	-5.50	4.48	677.5	-5.50	4.21	692.1	-5.50	3.97	702.6
FEB 7 NOV 5	-5.28	4.93	569.5	-5.28	4.61	595.1	-5.28	4.32	616.8	-5.28	4.07	634.2	-5.28	3.84	647.6
JAN 23 NOV 19	-5.09	4.75	514.4	-5.09	4.45	541.9	-5.09	4.18	565.6	-5.09	3.94	585.1	-5.09	3.73	600.4
JAN 10 DEC 3	-4.95	4.63	475.0	-4.95	4.34	503.6	-4.95	4.08	528.4	-4.95	3.85	549.1	-4.95	3.66	565.7
DEC 22	-4.86	4.55	451.7	-4.86	4.27	480.9	-4.86	4.02	506.3	-4.86	3.80	527.6	-4.86	3.61	544.9
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	277.064		.5271	281.311		.5352	284.161		.5406	285.649		.5435	285.908		.5440

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	18.4		30.1	16.0		33.5	13.8		36.5	11.7		39.1	9.9		41.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	4.55	929.3	-7.14	4.25	908.9	-7.14	3.98	888.4	-7.14	3.74	868.5	-7.14	3.52	849.1
JUN 1 JUL 12	-7.05	4.51	925.9	-7.05	4.21	906.7	-7.05	3.95	887.3	-7.05	3.71	866.3	-7.05	3.50	849.8
MAY 18 JUL 27	-6.91	4.44	918.8	-6.91	4.15	901.6	-6.91	3.90	884.0	-6.91	3.67	866.6	-6.91	3.46	849.5
MAY 3 AUG 10	-6.72	4.35	905.6	-6.72	4.08	891.3	-6.72	3.83	876.3	-6.72	3.61	861.1	-6.72	3.42	846.0
APR 19 AUG 25	-6.50	4.24	884.0	-6.50	3.98	873.2	-6.50	3.75	861.3	-6.50	3.54	848.8	-6.50	3.36	836.1
APR 4 SEP 9	-6.25	4.12	853.0	-6.25	3.88	846.0	-6.25	3.66	837.5	-6.25	3.47	828.1	-6.25	3.30	818.1
MAR 21 SEP 23	-6.00	4.00	811.5	-6.00	3.77	808.4	-6.00	3.57	803.5	-6.00	3.39	797.2	-6.00	3.23	790.0
MAR 7 OCT 6	-5.75	3.87	762.4	-5.75	3.66	763.0	-5.75	3.48	761.4	-5.75	3.31	758.1	-5.75	3.17	753.6
FEB 20 OCT 22	-5.50	3.75	709.5	-5.50	3.56	713.3	-5.50	3.39	714.6	-5.50	3.24	714.0	-5.50	3.10	712.0
FEB 7 NOV 5	-5.28	3.64	657.2	-5.28	3.46	663.6	-5.28	3.31	667.3	-5.28	3.17	668.9	-5.28	3.05	668.9
JAN 23 NOV 19	-5.09	3.55	612.0	-5.09	3.38	620.2	-5.09	3.24	625.7	-5.09	3.11	629.0	-5.09	3.00	630.6
JAN 10 DEC 3	-4.95	3.48	578.5	-4.95	3.33	588.0	-4.95	3.19	594.7	-4.95	3.07	599.0	-4.95	2.96	601.6
DEC 22	-4.86	3.44	558.3	-4.86	3.29	568.5	-4.86	3.16	575.7	-4.86	3.05	580.7	-4.86	2.94	583.9
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	285.134		.5429	283.547		.5395	281.365		.5353	278.782		.5304	275.930		.5250

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 34 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 33.8		ALPHA 6.9	THETA 33.3		ALPHA 13.6	THETA 32.4		ALPHA 19.9	THETA 31.3		ALPHA 25.8	THETA 30.0		ALPHA 31.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	6.67	1012.1	-7.14	6.20	1004.6	-7.14	5.74	993.1	-7.14	5.30	978.4	-7.14	4.90	961.7
JUN 1 JUL 12	-7.05	6.59	998.8	-7.05	6.12	991.6	-7.05	5.66	980.5	-7.05	5.23	966.4	-7.05	4.83	950.3
MAY 18 JUL 27	-6.91	6.45	974.9	-6.91	5.98	968.2	-6.91	5.53	957.8	-6.91	5.10	944.7	-6.91	4.71	929.7
MAY 3 AUG 10	-6.72	6.26	938.7	-6.72	5.80	932.7	-6.72	5.35	923.5	-6.72	4.93	911.7	-6.72	4.54	898.0
APR 19 AUG 25	-6.50	6.04	889.7	-6.50	5.58	884.6	-6.50	5.14	876.7	-6.50	4.73	866.5	-6.50	4.35	854.7
APR 4 SEP 9	-6.25	5.79	829.5	-6.25	5.34	825.4	-6.25	4.91	819.0	-6.25	4.51	810.6	-6.25	4.14	800.8
MAR 21 SEP 23	-6.00	5.54	759.3	-6.00	5.10	756.2	-6.00	4.67	751.4	-6.00	4.28	744.9	-6.00	3.93	737.1
MAR 7 OCT 8	-5.75	5.29	684.1	-5.75	4.85	682.1	-5.75	4.43	678.7	-5.75	4.05	674.0	-5.75	3.71	668.2
FEB 20 OCT 22	-5.50	5.05	609.5	-5.50	4.61	608.3	-5.50	4.21	606.3	-5.50	3.83	603.2	-5.50	3.50	599.3
FEB 7 NOV 5	-5.28	4.82	540.6	-5.28	4.39	540.2	-5.28	3.99	539.3	-5.28	3.63	537.6	-5.28	3.31	535.1
JAN 23 NOV 19	-5.09	4.64	484.0	-5.09	4.21	484.2	-5.09	3.82	484.1	-5.09	3.46	483.4	-5.09	3.15	482.1
JAN 10 DEC 3	-4.95	4.50	443.7	-4.95	4.07	444.2	-4.95	3.69	444.7	-4.95	3.34	444.7	-4.95	3.03	444.1
DEC 22	-4.86	4.41	420.0	-4.86	3.99	420.8	-4.86	3.61	421.5	-4.86	3.26	421.9	-4.86	2.96	421.7
	YEAR 271.117		R.I. .5158	YEAR 269.919		R.I. .5135	YEAR 268.006		R.I. .5099	YEAR 265.482		R.I. .5051	YEAR 262.478		R.I. .4994

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 28.7		ALPHA 35.9	THETA 27.3		ALPHA 40.2	THETA 25.9		ALPHA 44.0	THETA 24.6		ALPHA 47.3	THETA 23.3		ALPHA 50.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.14	4.52	943.8	-7.14	4.18	925.4	-7.14	3.88	907.1	-7.14	3.61	889.2	-7.14	3.36	872.0
JUN 1 JUL 12	-7.05	4.46	933.0	-7.05	4.12	915.2	-7.05	3.82	897.4	-7.05	3.55	880.1	-7.05	3.31	863.4
MAY 18 JUL 27	-6.91	4.34	913.4	-6.91	4.02	896.6	-6.91	3.72	879.9	-6.91	3.46	863.5	-6.91	3.22	847.5
MAY 3 AUG 10	-6.72	4.19	883.3	-6.72	3.87	868.0	-6.72	3.59	852.6	-6.72	3.33	837.5	-6.72	3.10	822.8
APR 19 AUG 25	-6.50	4.01	841.8	-6.50	3.70	828.3	-6.50	3.43	814.6	-6.50	3.18	801.1	-6.50	2.96	787.9
APR 4 SEP 9	-6.25	3.81	789.9	-6.25	3.52	778.4	-6.25	3.25	766.7	-6.25	3.02	755.1	-6.25	2.81	743.6
MAR 21 SEP 23	-6.00	3.61	728.4	-6.00	3.32	719.0	-6.00	3.07	709.4	-6.00	2.84	699.6	-6.00	2.64	690.0
MAR 7 OCT 8	-5.75	3.40	661.6	-5.75	3.13	654.3	-5.75	2.88	646.7	-5.75	2.67	638.8	-5.75	2.48	631.0
FEB 20 OCT 22	-5.50	3.20	594.5	-5.50	2.94	589.1	-5.50	2.71	583.2	-5.50	2.51	577.2	-5.50	2.33	570.9
FEB 7 NOV 5	-5.28	3.02	531.9	-5.28	2.77	528.1	-5.28	2.55	523.8	-5.28	2.36	519.2	-5.28	2.18	514.3
JAN 23 NOV 19	-5.09	2.87	480.0	-5.09	2.63	477.4	-5.09	2.41	474.3	-5.09	2.23	470.8	-5.09	2.06	467.0
JAN 10 DEC 3	-4.95	2.76	442.9	-4.95	2.52	441.0	-4.95	2.32	438.7	-4.95	2.14	435.9	-4.95	1.98	432.9
DEC 22	-4.86	2.69	420.9	-4.86	2.46	419.5	-4.86	2.26	417.6	-4.86	2.08	415.3	-4.86	1.92	412.6
	YEAR 259.131		R.I. .4930	YEAR 255.568		R.I. .4862	YEAR 251.909		R.I. .4793	YEAR 248.251		R.I. .4723	YEAR 244.633		R.I. .4654

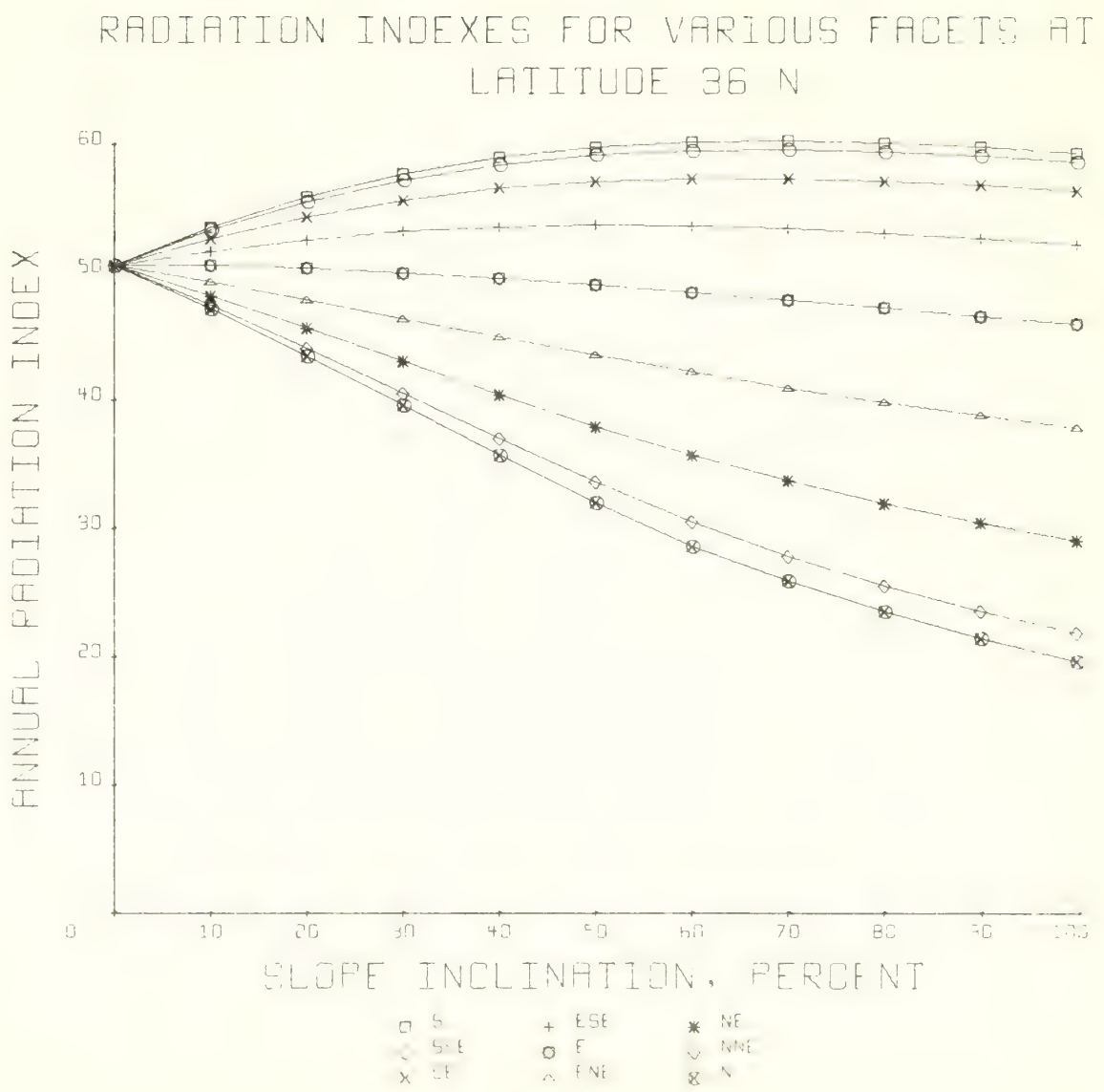
NOTE - FOR ASPECTS WITH WEST COMPONENTS. THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 36 N

		SR	SS	LY
JUN 22		-7.23	7.23	1018.3
JUN 1	JUL 12	-7.14	7.14	1003.2
MAY 18	JUL 27	-6.98	6.98	976.3
MAY 3	AUG 10	-6.78	6.78	936.0
APR 19	AUG 25	-6.54	6.54	882.2
APR 4	SEP 9	-6.27	6.27	817.0
MAR 21	SEP 23	-6.00	6.00	742.0
MAR 7	OCT 8	-5.73	5.73	662.5
FEB 20	OCT 22	-5.46	5.46	584.4
FEB 7	NOV 5	-5.22	5.22	513.1
JAN 23	NOV 19	-5.02	5.02	454.8
JAN 10	DEC 3	-4.86	4.86	413.6
DEC 22		-4.77	4.77	389.5

YEAR	R.I.
265.822	.5057



LATITUDE 56 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 41.7		ALPHA 0.0	THETA 47.5		ALPHA 0.0	THETA 52.7		ALPHA 0.0	THETA 57.8		ALPHA 0.0	THETA 62.6		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	7.23	1022.0	-7.23	7.23	1015.7	-7.23	7.23	1006.8	-7.23	7.23	978.1	-7.23	7.23	956.1
JUN 1 JUL 12	-7.14	7.14	1002.1	-7.14	7.14	991.4	-7.14	7.14	972.2	-7.14	7.14	946.0	-7.14	7.14	914.8
MAY 18 JUL 27	-6.98	6.98	967.3	-6.98	6.98	949.1	-6.98	6.98	923.2	-6.98	6.98	891.0	-6.98	6.98	854.6
MAY 3 AUG 10	-6.78	6.78	916.3	-6.78	6.78	888.1	-6.78	6.78	853.0	-6.78	6.78	812.6	-6.78	6.78	769.5
APR 19 AUG 25	-6.54	6.54	850.0	-6.54	6.54	810.3	-6.54	6.54	764.8	-6.54	6.54	715.4	-6.54	6.54	664.2
APR 4 SEP 9	-6.27	6.27	771.9	-6.27	6.27	720.2	-6.27	6.27	664.1	-6.27	6.27	605.5	-6.27	6.27	546.4
MAR 21 SEP 23	-6.00	6.00	684.6	-6.00	6.00	621.7	-6.00	6.00	555.7	-6.00	6.00	488.7	-6.00	6.00	422.5
MAR 7 OCT 8	-5.66	5.66	594.6	-5.59	5.59	522.5	-5.50	5.50	448.8	-5.40	5.40	375.7	-5.27	5.27	305.0
FEB 20 OCT 22	-5.34	5.34	508.5	-5.20	5.20	430.0	-5.02	5.02	351.7	-4.81	4.81	276.0	-4.55	4.55	204.9
FEB 7 NOV 5	-5.04	5.04	431.7	-4.83	4.83	349.6	-4.57	4.57	269.6	-4.25	4.25	194.4	-3.83	3.83	126.5
JAN 23 NOV 19	-4.78	4.78	370.4	-4.51	4.51	286.8	-4.17	4.17	207.2	-3.74	3.74	134.8	-3.17	3.17	72.5
JAN 10 DEC 3	-4.60	4.60	327.7	-4.27	4.27	243.9	-3.87	3.87	165.8	-3.34	3.34	96.8	-2.60	2.60	40.6
DEC 22	-4.48	4.48	303.0	-4.12	4.12	219.6	-3.68	3.68	142.8	-3.09	3.09	76.4	-2.21	2.21	24.9
	YEAR 248.001		R.I. .4718	YEAR 228.506		R.I. .4348	YEAR 208.159		R.I. .3960	YEAR 187.790		R.I. .3573	YEAR 168.274		R.I. .3202

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 67.0		ALPHA 0.0	THETA 71.0		ALPHA 0.0	THETA 74.7		ALPHA 0.0	THETA 78.0		ALPHA 0.0	THETA 81.0		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	7.23	918.4	-7.23	7.23	884.5	-7.23	7.23	850.0	-7.23	7.23	815.7	-7.23	7.23	782.1
JUN 1 JUL 12	-7.14	7.14	880.4	-7.14	7.14	844.3	-7.14	7.14	807.8	-7.14	7.14	772.0	-7.14	7.14	737.1
MAY 18 JUL 27	-6.98	6.98	815.7	-6.98	6.98	775.9	-6.98	6.98	736.3	-6.98	6.98	697.9	-6.98	6.98	660.9
MAY 3 AUG 10	-6.78	6.78	724.7	-6.78	6.78	679.9	-6.78	6.78	636.3	-6.78	6.78	594.5	-6.78	6.78	554.8
APR 19 AUG 25	-6.54	6.54	612.8	-6.54	6.54	562.5	-6.54	6.54	514.4	-6.54	6.54	469.0	-6.54	6.54	426.3
APR 4 SEP 9	-6.27	6.27	488.4	-6.27	6.27	432.8	-6.27	6.27	380.3	-6.27	6.27	331.6	-6.27	6.27	286.2
MAR 21 SEP 23	-6.00	6.00	358.8	-6.00	6.00	298.6	-6.00	6.00	242.5	-6.00	6.00	190.9	-6.00	6.00	143.4
MAR 7 OCT 8	-5.11	5.11	238.5	-4.89	4.89	177.1	-4.59	4.59	121.7	-4.16	4.16	73.1	-3.43	3.43	32.0
FEB 20 OCT 22	-4.20	4.20	140.4	-3.73	3.73	83.8	-3.02	3.02	37.4	-1.67	1.67	5.2	0.00	0.00	0.0
FEB 7 NOV 5	-3.27	3.27	68.4	-2.39	2.39	23.2	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	-2.29	2.29	24.2	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	-1.23	1.23	3.8	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 150.704		R.I. .2867	YEAR 136.107		R.I. .2590	YEAR 123.629		R.I. .2352	YEAR 112.820		R.I. .2147	YEAR 103.429		R.I. .1968

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 36 N
ASPECT S -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 30.3		ALPHA 0.0	THETA 24.7		ALPHA 0.0	THETA 19.3		ALPHA 0.0	THETA 14.2		ALPHA 0.0	THETA 9.4		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.98	6.98	1005.9	-6.77	6.77	986.5	-6.58	6.58	960.8	-6.42	6.42	930.1	-6.28	6.28	896.1
JUN 1 JUL 12	-6.91	6.91	995.5	-6.71	6.71	980.5	-6.54	6.54	958.8	-6.39	6.39	931.8	-6.26	6.26	901.0
MAY 18 JUL 27	-6.79	6.79	976.5	-6.62	6.62	968.9	-6.47	6.47	954.1	-6.34	6.34	933.4	-6.22	6.22	908.1
MAY 3 AUG 10	-6.62	6.62	947.0	-6.49	6.49	949.7	-6.37	6.37	944.6	-6.27	6.27	932.7	-6.18	6.18	915.4
APR 19 AUG 25	-6.43	6.43	905.9	-6.34	6.34	920.9	-6.26	6.26	927.5	-6.19	6.19	926.4	-6.12	6.12	919.1
APR 4 SEP 9	-6.22	6.22	854.1	-6.17	6.17	882.3	-6.13	6.13	901.6	-6.10	6.10	912.6	-6.06	6.06	916.5
MAR 21 SEP 23	-6.00	6.00	792.0	-6.00	6.00	833.3	-6.00	6.00	865.6	-6.00	6.00	889.1	-6.00	6.00	904.7
MAR 7 OCT 8	-5.73	5.73	723.9	-5.73	5.73	777.1	-5.73	5.73	821.2	-5.73	5.73	856.3	-5.73	5.73	883.0
FEB 20 OCT 22	-5.46	5.46	654.9	-5.46	5.46	717.6	-5.46	5.46	771.4	-5.46	5.46	816.1	-5.46	5.46	852.1
FEB 7 NOV 5	-5.22	5.22	590.0	-5.22	5.22	659.7	-5.22	5.22	720.8	-5.22	5.22	772.8	-5.22	5.22	815.9
JAN 23 NOV 19	-5.02	5.02	535.9	-5.02	5.02	610.2	-5.02	5.02	676.1	-5.02	5.02	733.1	-5.02	5.02	781.0
JAN 10 DEC 3	-4.86	4.86	496.9	-4.86	4.86	573.8	-4.86	4.86	642.5	-4.86	4.86	702.4	-4.86	4.86	753.4
DEC 22	-4.77	4.77	473.8	-4.77	4.77	551.9	-4.77	4.77	622.0	-4.77	4.77	683.4	-4.77	4.77	735.9
	YEAR 281.274		R.I. .5351	YEAR 293.920		R.I. .5592	YEAR 303.608		R.I. .5776	YEAR 310.456		R.I. .5907	YEAR 314.747		R.I. .5988

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 5.0		ALPHA 0.0	THETA 1.0		ALPHA 0.0	THETA -3.7		ALPHA 0.0	THETA -8.3		ALPHA 0.0	THETA -90.		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.15	6.15	860.1	-6.03	6.03	823.5	-5.92	5.92	787.3	-5.83	5.83	752.3	-5.74	5.74	718.6
JUN 1 JUL 12	-6.14	6.14	867.9	-6.03	6.03	833.7	-5.93	5.93	799.6	-5.84	5.84	766.5	-5.76	5.76	734.5
MAY 18 JUL 27	-6.12	6.12	879.9	-6.02	6.02	850.0	-5.94	5.94	819.7	-5.86	5.86	789.7	-5.79	5.79	760.4
MAY 3 AUG 10	-6.09	6.09	894.2	-6.02	6.02	870.6	-5.95	5.95	845.6	-5.89	5.89	820.3	-5.83	5.83	795.1
APR 19 AUG 25	-6.06	6.06	906.9	-6.01	6.01	891.1	-5.97	5.97	873.4	-5.92	5.92	853.9	-5.88	5.88	834.1
APR 4 SEP 9	-6.03	6.03	914.5	-6.01	6.01	907.9	-5.98	5.98	898.1	-5.96	5.96	886.1	-5.94	5.94	872.6
MAR 21 SEP 23	-6.00	6.00	913.6	-6.00	6.00	917.3	-6.00	6.00	916.1	-6.00	6.00	912.1	-6.00	6.00	905.8
MAR 7 OCT 8	-5.73	5.73	902.2	-5.73	5.73	915.2	-5.73	5.73	923.1	-5.73	5.73	926.9	-5.73	5.73	927.7
FEB 20 OCT 22	-5.46	5.46	886.1	-5.46	5.46	901.2	-5.46	5.46	910.5	-5.46	5.46	917.1	-5.46	5.46	920.0
FEB 7 NOV 5	-5.22	5.22	850.7	-5.22	5.22	878.1	-5.22	5.22	894.3	-5.22	5.22	904.6	-5.22	5.22	909.2
JAN 23 NOV 19	-5.02	5.02	820.6	-5.02	5.02	852.6	-5.02	5.02	877.9	-5.02	5.02	897.8	-5.02	5.02	913.3
JAN 10 DEC 3	-4.86	4.86	792.8	-4.86	4.86	830.5	-4.86	4.86	858.6	-4.86	4.86	880.9	-4.86	4.86	898.7
DEC 22	-4.77	4.77	779.8	-4.77	4.77	818.3	-4.77	4.77	845.4	-4.77	4.77	867.1	-4.77	4.77	885.1
	YEAR 316.867		R.I. .6046	YEAR 316.244		R.I. .6036	YEAR 316.285		R.I. .6018	YEAR 314.259		R.I. .5981	YEAR 311.722		R.I. .5931

NOTE - FOR ASPECTS WITH E-W COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 36 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	41.2		2.9	46.3		6.2	51.1		10.1	55.4		14.5	59.3		19.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	7.23	1021.3	-7.23	7.23	1014.4	-7.23	7.23	998.7	-7.23	7.23	975.6	-7.23	7.23	947.1
JUN 1 JUL 12	-7.14	7.14	1001.8	-7.14	7.14	990.8	-7.14	7.14	971.3	-7.14	7.14	944.9	-7.14	7.14	913.5
MAY 18 JUL 27	-6.98	6.98	967.6	-6.98	6.98	949.8	-6.98	6.98	924.1	-6.98	6.98	892.2	-6.98	6.98	856.0
MAY 3 AUG 10	-6.78	6.75	917.4	-6.78	6.72	890.4	-6.78	6.67	856.4	-6.78	6.62	817.3	-6.78	6.56	774.9
APR 19 AUG 25	-6.54	6.46	852.2	-6.54	6.36	814.7	-6.54	6.25	771.6	-6.54	6.12	724.8	-6.54	5.96	676.1
APR 4 SEP 9	-6.27	6.14	775.2	-6.27	5.98	727.3	-6.27	5.80	675.3	-6.27	5.58	621.3	-6.27	5.33	567.2
MAR 21 SEP 23	-6.00	5.81	689.1	-6.00	5.58	631.7	-6.00	5.33	572.0	-6.00	5.03	512.2	-6.00	4.69	454.4
MAR 7 OCT 8	-5.73	5.48	600.2	-5.73	5.19	535.0	-5.73	4.86	469.5	-5.73	4.48	406.0	-5.73	4.06	346.5
FEB 20 OCT 22	-5.46	5.16	514.8	-5.46	4.81	444.1	-5.46	4.41	375.1	-5.46	3.95	310.0	-5.46	3.43	250.8
FEB 7 NOV 5	-5.22	4.86	438.5	-5.22	4.45	364.5	-5.22	3.98	293.9	-5.22	3.44	229.2	-5.22	2.82	172.2
JAN 23 NOV 19	-5.00	4.61	377.3	-4.98	4.15	301.8	-4.96	3.61	231.3	-4.93	2.99	168.1	-4.89	2.28	114.2
JAN 10 DEC 3	-4.81	4.43	334.7	-4.75	3.92	258.9	-4.68	3.33	189.3	-4.58	2.65	128.2	-4.45	1.84	77.7
DEC 22	-4.70	4.31	310.1	-4.61	3.78	234.4	-4.50	3.16	165.7	-4.36	2.43	106.4	-4.16	1.55	58.5
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	249.395		.4745	231.522		.4405	212.994		.4052	194.569		.3702	176.968		.3367

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	62.7		25.4	65.5		32.0	67.8		39.3	69.5		47.1	70.8		55.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	7.23	914.9	-7.23	7.23	880.7	-7.23	7.23	845.8	-7.23	7.23	811.2	-7.23	7.23	777.4
JUN 1 JUL 12	-7.14	7.14	878.9	-7.14	7.14	842.6	-7.14	7.14	806.0	-7.14	7.14	770.0	-7.14	7.14	735.0
MAY 18 JUL 27	-6.98	6.98	817.4	-6.98	6.98	777.7	-6.98	6.98	738.3	-6.98	6.98	700.0	-6.98	6.98	663.2
MAY 3 AUG 10	-6.78	6.49	731.1	-6.78	6.39	687.2	-6.78	6.26	644.5	-6.78	6.09	603.8	-6.78	5.86	565.2
APR 19 AUG 25	-6.54	5.77	627.4	-6.54	5.54	580.1	-6.54	5.26	535.3	-6.54	4.94	493.7	-6.54	4.56	455.5
APR 4 SEP 9	-6.27	5.04	514.9	-6.27	4.70	465.6	-6.27	4.31	420.4	-6.27	3.88	379.8	-6.27	3.41	343.8
MAR 21 SEP 23	-6.00	4.31	400.3	-6.00	3.87	351.0	-6.00	3.38	307.3	-6.00	2.86	269.5	-6.00	2.32	237.3
MAR 7 OCT 8	-5.73	3.57	292.6	-5.73	3.03	245.2	-5.73	2.45	205.0	-5.73	1.84	171.7	-5.73	1.23	144.8
FEB 20 OCT 22	-5.46	2.84	199.1	-5.46	2.19	155.6	-5.46	1.50	120.4	-5.46	.79	93.1	-5.46	.08	72.5
FEB 7 NOV 5	-5.22	2.13	124.2	-5.22	1.35	85.9	-5.22	.51	57.0	-5.22	-.36	36.7	-5.22	-1.22	23.2
JAN 23 NOV 19	-4.84	1.45	70.9	-4.77	.50	38.5	-4.66	-.57	16.7	-4.47	-1.81	4.3	0.00	0.00	0.0
JAN 10 DEC 3	-4.27	.88	39.2	-3.97	-.30	13.2	-3.19	-2.05	.4	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-3.87	.48	23.7	-3.28	-.99	3.2	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	160.778		.3059	146.400		.2785	134.172		.2553	123.799		.2355	114.763		.2183

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 36 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 30.7		ALPHA 2.5	THETA 25.4		ALPHA 4.8	THETA 20.4		ALPHA 6.7	THETA 15.6		ALPHA 8.5	THETA 11.0		ALPHA 10.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.17	6.83	1007.0	-7.11	6.48	989.5	-7.07	6.17	966.5	-7.03	5.90	938.9	-6.99	5.65	908.1
JUN 1 JUL 12	-7.09	6.75	996.3	-7.06	6.42	983.0	-7.02	6.13	963.7	-7.00	5.86	939.6	-6.97	5.63	912.0
MAY 18 JUL 27	-6.97	6.63	976.7	-6.96	6.32	970.4	-6.95	6.05	957.7	-6.94	5.81	939.5	-6.93	5.59	917.3
MAY 3 AUG 10	-6.78	6.47	946.5	-6.78	6.19	949.8	-6.78	5.95	946.1	-6.78	5.73	936.4	-6.78	5.54	921.7
APR 19 AUG 25	-6.54	6.27	904.4	-6.54	6.03	919.1	-6.54	5.82	926.3	-6.54	5.64	926.6	-6.54	5.47	921.1
APR 4 SEP 9	-6.27	6.05	851.5	-6.27	5.86	878.2	-6.27	5.69	896.9	-6.27	5.54	908.1	-6.27	5.40	912.5
MAR 21 SEP 23	-6.00	5.83	788.3	-6.00	5.68	826.7	-6.00	5.55	856.7	-6.00	5.43	878.7	-6.00	5.33	893.2
MAR 7 OCT 8	-5.73	5.61	719.2	-5.73	5.50	768.1	-5.73	5.41	808.4	-5.73	5.33	840.3	-5.73	5.26	864.3
FEB 20 OCT 22	-5.46	5.39	649.4	-5.46	5.33	706.8	-5.46	5.28	755.8	-5.46	5.23	796.1	-5.46	5.19	828.2
FEB 7 NOV 5	-5.22	5.20	584.0	-5.22	5.17	647.8	-5.22	5.15	703.4	-5.22	5.14	750.3	-5.22	5.12	788.9
JAN 23 NOV 19	-5.02	5.02	529.6	-5.02	5.02	597.7	-5.02	5.02	657.8	-5.02	5.02	709.4	-5.02	5.02	752.6
JAN 10 DEC 3	-4.86	4.86	490.4	-4.86	4.86	561.0	-4.86	4.86	623.8	-4.86	4.86	678.2	-4.86	4.86	724.2
DEC 22	-4.77	4.77	467.3	-4.77	4.77	539.0	-4.77	4.77	603.1	-4.77	4.77	658.9	-4.77	4.77	706.4
	YEAR 280.122		R.I. .5330	YEAR 291.856		R.I. .5553	YEAR 300.855		R.I. .5724	YEAR 307.211		R.I. .5845	YEAR 311.180		R.I. .5920

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 6.9		ALPHA 11.4	THETA 3.0		ALPHA 12.7	THETA -0.5		ALPHA 13.8	THETA -3.6		ALPHA 14.9	THETA -6.5		ALPHA 15.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.96	5.44	875.5	-6.93	5.24	842.3	-6.91	5.06	809.4	-6.89	4.90	777.5	-6.86	4.76	746.9
JUN 1 JUL 12	-6.95	5.42	882.2	-6.93	5.23	851.3	-6.91	5.07	820.5	-6.89	4.91	790.4	-6.88	4.77	761.3
MAY 18 JUL 27	-6.92	5.40	892.2	-6.92	5.22	865.5	-6.91	5.07	838.3	-6.91	4.92	811.3	-6.90	4.79	785.0
MAY 3 AUG 10	-6.78	5.37	903.4	-6.78	5.21	882.7	-6.78	5.07	860.8	-6.78	4.94	838.4	-6.78	4.83	815.9
APR 19 AUG 25	-6.54	5.33	911.1	-6.54	5.19	897.7	-6.54	5.07	882.2	-6.54	4.96	865.5	-6.54	4.86	848.0
APR 4 SEP 9	-6.27	5.28	911.6	-6.27	5.17	906.3	-6.27	5.07	898.0	-6.27	4.99	887.6	-6.27	4.90	875.7
MAR 21 SEP 23	-6.00	5.24	901.5	-6.00	5.15	904.6	-6.00	5.08	903.8	-6.00	5.01	900.0	-6.00	4.95	894.0
MAR 7 OCT 8	-5.73	5.19	881.3	-5.73	5.13	892.4	-5.73	5.08	898.7	-5.73	5.03	901.4	-5.73	4.99	901.2
FEB 20 OCT 22	-5.46	5.15	852.8	-5.46	5.11	870.9	-5.46	5.08	883.7	-5.46	5.06	892.2	-5.46	5.03	897.3
FEB 7 NOV 5	-5.22	5.11	819.6	-5.22	5.10	843.5	-5.22	5.09	861.6	-5.22	5.08	875.0	-5.22	5.07	884.6
JAN 23 NOV 19	-5.02	5.02	787.8	-5.02	5.02	816.0	-5.02	5.02	838.1	-5.02	5.02	855.2	-5.02	5.02	868.3
JAN 10 DEC 3	-4.86	4.86	762.2	-4.86	4.86	793.1	-4.86	4.86	817.8	-4.86	4.86	837.3	-4.86	4.86	852.5
DEC 22	-4.77	4.77	745.8	-4.77	4.77	778.2	-4.77	4.77	804.2	-4.77	4.77	825.0	-4.77	4.77	841.4
	YEAR 313.117		R.I. .5957	YEAR 313.420		R.I. .5963	YEAR 312.471		R.I. .5945	YEAR 310.610		R.I. .5910	YEAR 308.096		R.I. .5862

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 36 N
ASPECT NE - NW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	39.9		5.3	43.5		11.0	46.7		17.2	49.3		23.7	51.4		30.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	7.07	1019.7	-7.23	6.89	1011.7	-7.23	6.68	995.7	-7.23	6.44	973.2	-7.23	6.17	946.2
JUN 1 JUL 12	-7.14	6.96	1001.3	-7.14	6.77	990.4	-7.14	6.54	971.9	-7.14	6.28	947.4	-7.14	5.99	919.0
MAY 18 JUL 27	-6.98	6.79	968.9	-6.98	6.56	953.2	-6.98	6.31	930.8	-6.98	6.02	903.2	-6.98	5.71	872.4
MAY 3 AUG 10	-6.78	6.55	921.3	-6.78	6.29	899.3	-6.78	6.00	871.5	-6.78	5.68	839.9	-6.78	5.33	806.3
APR 19 AUG 25	-6.54	6.27	859.0	-6.54	5.97	829.8	-6.54	5.64	796.3	-6.54	5.28	760.5	-6.54	4.90	724.1
APR 4 SEP 9	-6.27	5.96	785.0	-6.27	5.62	748.6	-6.27	5.25	709.7	-6.27	4.86	670.0	-6.27	4.44	631.4
MAR 21 SEP 23	-6.00	5.65	701.8	-6.00	5.26	658.9	-6.00	4.85	615.2	-6.00	4.42	572.6	-6.00	3.97	532.6
MAR 7 OCT 8	-5.73	5.33	615.3	-5.73	4.91	567.2	-5.73	4.45	520.1	-5.73	3.98	475.8	-5.73	3.50	435.5
FEB 20 OCT 22	-5.46	5.03	531.9	-5.46	4.56	480.0	-5.46	4.07	431.0	-5.46	3.55	386.2	-5.46	3.04	346.7
FEB 7 NOV 5	-5.22	4.75	456.9	-5.22	4.24	402.9	-5.22	3.71	353.2	-5.22	3.16	309.0	-5.22	2.61	271.1
JAN 23 NOV 19	-5.02	4.51	396.5	-5.02	3.97	341.6	-5.02	3.40	292.1	-5.02	2.81	249.1	-5.02	2.23	213.2
JAN 10 DEC 3	-4.86	4.33	354.3	-4.86	3.76	299.2	-4.86	3.16	250.3	-4.86	2.55	208.6	-4.86	1.95	174.4
DEC 22	-4.77	4.23	329.7	-4.77	3.64	274.8	-4.77	3.02	226.5	-4.77	2.39	185.7	-4.77	1.77	152.7
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	253.303		.4819	239.829		.4563	226.038		.4301	212.499		.4043	199.685		.3799

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	53.0		37.2	54.1		43.7	54.7		49.9	55.0		55.6	55.1		60.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	5.87	916.6	-7.23	5.54	886.0	-7.23	5.20	855.8	-7.23	4.85	826.9	-7.23	4.51	799.7
JUN 1 JUL 12	-7.14	5.68	888.4	-7.14	5.34	857.2	-7.14	4.99	826.8	-7.14	4.64	797.9	-7.14	4.29	770.8
MAY 18 JUL 27	-6.98	5.37	840.3	-6.98	5.02	808.3	-6.98	4.66	777.5	-6.98	4.30	748.7	-6.98	3.95	722.0
MAY 3 AUG 10	-6.78	4.97	772.5	-6.78	4.59	739.6	-6.78	4.22	708.7	-6.78	3.86	680.2	-6.78	3.51	654.3
APR 19 AUG 25	-6.54	4.51	688.7	-6.54	4.11	655.3	-6.54	3.73	624.6	-6.54	3.36	597.0	-6.54	3.01	572.2
APR 4 SEP 9	-6.27	4.02	595.0	-6.27	3.61	561.7	-6.27	3.21	531.8	-6.27	2.83	505.5	-6.27	2.48	482.3
MAR 21 SEP 23	-6.00	3.52	496.2	-6.00	3.09	463.7	-6.00	2.67	435.4	-6.00	2.29	411.0	-6.00	1.94	389.9
MAR 7 OCT 8	-5.73	3.02	399.9	-5.73	2.56	369.1	-5.73	2.14	343.0	-5.73	1.75	320.9	-5.73	1.40	302.3
FEB 20 OCT 22	-5.46	2.53	312.8	-5.46	2.06	284.3	-5.46	1.62	260.8	-5.46	1.22	241.5	-5.46	.87	225.5
FEB 7 NOV 5	-5.22	2.08	239.5	-5.22	1.58	213.7	-5.22	1.13	192.9	-5.22	.72	176.3	-5.22	.37	162.9
JAN 23 NOV 19	-5.02	1.67	184.0	-5.02	1.16	160.8	-5.02	.69	142.6	-5.02	.28	128.4	-5.02	-.07	117.3
JAN 10 DEC 3	-4.86	1.37	147.2	-4.86	.83	126.1	-4.86	.36	109.9	-4.86	-.06	97.6	-4.86	-.42	88.1
DEC 22	-4.77	1.18	126.8	-4.77	.63	107.0	-4.77	.14	92.1	-4.77	-.27	80.9	-4.77	-.63	72.5
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	187.916		.3575	177.330		.3374	167.973		.3196	159.789		.3040	152.609		.2904

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 36 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 31.9		ALPHA 4.8	THETA 27.7		ALPHA 9.0	THETA 23.5		ALPHA 12.8	THETA 19.5		ALPHA 16.2	THETA 15.7		ALPHA 19.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	6.73	1009.9	-7.23	6.28	996.9	-7.23	5.87	979.8	-7.23	5.51	959.2	-7.23	5.19	935.9
JUN 1 JUL 12	-7.14	6.65	998.1	-7.14	6.21	988.4	-7.14	5.82	974.3	-7.14	5.47	956.5	-7.14	5.15	935.7
MAY 18 JUL 27	-6.98	6.52	976.9	-6.98	6.11	972.6	-6.98	5.73	963.5	-6.98	5.40	950.3	-6.98	5.10	933.8
MAY 3 AUG 10	-6.78	6.35	944.3	-6.78	5.96	947.4	-6.78	5.61	945.3	-6.78	5.30	938.5	-6.78	5.02	927.7
APR 19 AUG 25	-6.54	6.14	899.5	-6.54	5.79	911.3	-6.54	5.47	917.4	-6.54	5.18	918.2	-6.54	4.93	914.3
APR 4 SEP 9	-6.27	5.92	843.7	-6.27	5.60	864.6	-6.27	5.31	879.4	-6.27	5.06	888.3	-6.27	4.83	891.9
MAR 21 SEP 23	-6.00	5.68	777.6	-6.00	5.40	807.3	-6.00	5.15	830.6	-6.00	4.92	847.5	-6.00	4.72	858.6
MAR 7 OCT 8	-5.73	5.45	706.0	-5.73	5.20	743.6	-5.73	4.98	774.5	-5.73	4.79	798.7	-5.73	4.62	816.6
FEB 20 OCT 22	-5.46	5.22	634.1	-5.46	5.01	678.1	-5.46	4.83	715.3	-5.46	4.66	745.5	-5.46	4.52	769.2
FEB 7 NOV 5	-5.22	5.02	567.3	-5.22	4.84	615.8	-5.22	4.68	657.7	-5.22	4.54	692.6	-5.22	4.42	720.8
JAN 23 NOV 19	-5.02	4.84	511.9	-5.02	4.69	563.5	-5.02	4.56	608.5	-5.02	4.45	646.7	-5.02	4.35	678.0
JAN 10 DEC 3	-4.86	4.71	472.2	-4.86	4.59	525.5	-4.86	4.47	572.4	-4.86	4.38	612.5	-4.86	4.29	645.8
DEC 22	-4.77	4.64	448.8	-4.77	4.52	502.9	-4.77	4.42	550.8	-4.77	4.33	591.8	-4.77	4.26	626.2
	YEAR 276.797		R.I. .5266	YEAR 285.822		R.I. .5438	YEAR 292.712		R.I. .5569	YEAR 297.501		R.I. .5660	YEAR 300.375		R.I. .5715

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 12.1		ALPHA 21.8	THETA 8.8		ALPHA 24.2	THETA 5.8		ALPHA 26.4	THETA 3.1		ALPHA 28.3	THETA .6		ALPHA 30.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	4.90	911.1	-7.23	4.64	885.6	-7.23	4.41	860.1	-7.23	4.21	835.3	-7.23	4.02	811.3
JUN 1 JUL 12	-7.14	4.87	913.1	-7.14	4.62	889.5	-7.14	4.40	865.7	-7.14	4.20	842.3	-7.14	4.02	819.5
MAY 18 JUL 27	-6.98	4.83	914.9	-6.98	4.59	894.5	-6.98	4.38	873.5	-6.98	4.19	852.6	-6.98	4.01	831.9
MAY 3 AUG 10	-6.78	4.77	913.9	-6.78	4.55	898.1	-6.78	4.35	881.1	-6.78	4.17	863.6	-6.78	4.01	846.0
APR 19 AUG 25	-6.54	4.70	906.8	-6.54	4.50	896.5	-6.54	4.32	884.3	-6.54	4.16	871.0	-6.54	4.01	857.0
APR 4 SEP 9	-6.27	4.62	891.1	-6.27	4.44	886.8	-6.27	4.28	879.9	-6.27	4.14	871.3	-6.27	4.00	861.4
MAR 21 SEP 23	-6.00	4.54	864.5	-6.00	4.38	866.3	-6.00	4.24	864.9	-6.00	4.12	861.1	-6.00	4.00	855.6
MAR 7 OCT 8	-5.73	4.46	828.8	-5.73	4.33	836.4	-5.73	4.20	840.1	-5.73	4.09	841.0	-5.73	4.00	839.6
FEB 20 OCT 22	-5.46	4.39	786.8	-5.46	4.27	799.4	-5.46	4.17	807.7	-5.46	4.08	812.6	-5.46	3.99	815.0
FEB 7 NOV 5	-5.22	4.32	742.7	-5.22	4.22	759.3	-5.22	4.13	771.4	-5.22	4.06	779.7	-5.22	3.99	785.2
JAN 23 NOV 19	-5.02	4.26	703.0	-5.02	4.18	722.5	-5.02	4.11	737.3	-5.02	4.04	748.2	-5.02	3.98	756.1
JAN 10 DEC 3	-4.86	4.21	672.8	-4.86	4.15	694.2	-4.86	4.09	710.8	-4.86	4.03	723.3	-4.86	3.98	732.7
DEC 22	-4.77	4.19	654.2	-4.77	4.13	676.6	-4.77	4.07	694.1	-4.77	4.02	707.6	-4.77	3.98	717.9
	YEAR 301.608		R.I. .5738	YEAR 301.519		R.I. .5737	YEAR 300.419		R.I. .5716	YEAR 298.586		R.I. .5681	YEAR 296.232		R.I. .5636

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 36 N
ASPECT ENE - WNW

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	38.0	6.7	39.6	13.6	40.7	20.5	41.4	27.2	41.6	33.6

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	6.88	1017.8	-7.23	6.50	1010.3	-7.23	6.10	997.0	-7.23	5.69	979.3	-7.23	5.28	959.0
JUN 1 JUL 12	-7.14	6.78	1001.0	-7.14	6.39	992.2	-7.14	5.99	977.9	-7.14	5.57	959.7	-7.14	5.16	939.0
MAY 18 JUL 27	-6.98	6.61	971.3	-6.98	6.22	960.3	-6.98	5.80	944.5	-6.98	5.39	925.3	-6.98	4.97	904.2
MAY 3 AUG 10	-6.78	6.39	927.3	-6.78	5.98	913.3	-6.78	5.56	895.5	-6.78	5.13	875.2	-6.78	4.72	853.6
APR 19 AUG 25	-6.54	6.13	869.1	-6.54	5.70	852.0	-6.54	5.27	832.0	-6.54	4.84	810.5	-6.54	4.42	788.5
APR 4 SEP 9	-6.27	5.85	799.4	-6.27	5.40	779.1	-6.27	4.96	757.1	-6.27	4.52	734.7	-6.27	4.10	712.5
MAR 21 SEP 23	-6.00	5.55	720.2	-6.00	5.09	697.0	-6.00	4.63	673.4	-6.00	4.19	650.3	-6.00	3.76	628.5
MAR 7 OCT 8	-5.73	5.26	637.1	-5.73	4.78	611.7	-5.73	4.31	587.0	-5.73	3.85	563.9	-5.73	3.43	542.6
FEB 20 OCT 22	-5.46	4.98	556.4	-5.46	4.48	529.3	-5.46	4.00	504.2	-5.46	3.54	481.4	-5.46	3.11	461.1
FEB 7 NOV 5	-5.22	4.71	483.2	-5.22	4.20	455.3	-5.22	3.71	430.2	-5.22	3.24	408.1	-5.22	2.81	388.9
JAN 23 NOV 19	-5.02	4.49	423.9	-5.02	3.97	395.7	-5.02	3.46	370.9	-5.02	2.99	349.6	-5.02	2.55	331.5
JAN 10 DEC 3	-4.86	4.33	382.1	-4.86	3.79	354.0	-4.86	3.28	329.6	-4.86	2.80	309.0	-4.86	2.36	291.9
DEC 22	-4.77	4.23	357.8	-4.77	3.69	329.8	-4.77	3.17	305.8	-4.77	2.69	285.6	-4.77	2.25	269.0

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
258.989	.4928	251.546	.4786	243.848	.4639	236.190	.4494	228.806	.4353

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	41.6	39.4	41.2	44.8	40.7	49.6	40.1	53.9	39.4	57.7

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	4.88	937.4	-7.23	4.51	915.4	-7.23	4.16	893.9	-7.23	3.84	873.4	-7.23	3.55	854.0
JUN 1 JUL 12	-7.14	4.77	917.3	-7.14	4.39	895.4	-7.14	4.05	874.1	-7.14	3.73	853.9	-7.14	3.44	834.8
MAY 18 JUL 27	-6.98	4.58	882.4	-6.98	4.21	860.7	-6.98	3.86	839.8	-6.98	3.55	820.1	-6.98	3.27	801.5
MAY 3 AUG 10	-6.78	4.33	831.8	-6.78	3.96	810.5	-6.78	3.62	790.2	-6.78	3.31	771.2	-6.78	3.04	753.5
APR 19 AUG 25	-6.54	4.03	766.9	-6.54	3.66	746.2	-6.54	3.33	726.8	-6.54	3.03	708.9	-6.54	2.76	692.2
APR 4 SEP 9	-6.27	3.71	691.4	-6.27	3.34	671.6	-6.27	3.02	653.4	-6.27	2.73	636.7	-6.27	2.46	621.4
MAR 21 SEP 23	-6.00	3.37	608.2	-6.00	3.01	589.6	-6.00	2.69	572.7	-6.00	2.41	557.6	-6.00	2.15	543.8
MAR 7 OCT 8	-5.73	3.04	523.4	-5.73	2.68	506.3	-5.73	2.37	491.0	-5.73	2.09	477.5	-5.73	1.84	465.3
FEB 20 OCT 22	-5.46	2.71	443.2	-5.46	2.36	427.6	-5.46	2.06	414.0	-5.46	1.78	402.1	-5.46	1.55	391.5
FEB 7 NOV 5	-5.22	2.42	372.4	-5.22	2.07	358.3	-5.22	1.77	346.3	-5.22	1.50	335.8	-5.22	1.27	326.7
JAN 23 NOV 19	-5.02	2.16	316.4	-5.02	1.82	303.6	-5.02	1.52	292.8	-5.02	1.26	283.7	-5.02	1.04	275.7
JAN 10 DEC 3	-4.86	1.97	277.7	-4.86	1.63	265.9	-4.86	1.34	256.0	-4.86	1.08	247.8	-4.86	.86	240.7
DEC 22	-4.77	1.86	255.4	-4.77	1.52	244.2	-4.77	1.23	235.0	-4.77	.98	227.2	-4.77	.76	220.6

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
221.851	.4221	215.395	.4098	209.475	.3985	204.086	.3883	199.158	.3789

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 36 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	33.6		6.3	31.0		12.2	28.3		17.5	25.5		22.3	22.8		26.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	6.70	1013.0	-7.23	6.20	1003.8	-7.23	5.73	991.2	-7.23	5.31	975.8	-7.23	4.93	958.2
JUN 1 JUL 12	-7.14	6.61	999.7	-7.14	6.12	992.5	-7.14	5.67	981.7	-7.14	5.25	968.0	-7.14	4.88	952.1
MAY 18 JUL 27	-6.98	6.48	976.0	-6.98	6.00	971.9	-6.98	5.56	964.2	-6.98	5.15	953.4	-6.98	4.79	940.2
MAY 3 AUG 10	-6.78	6.29	940.0	-6.78	5.83	940.2	-6.78	5.41	936.8	-6.78	5.02	930.0	-6.78	4.67	920.4
APR 19 AUG 25	-6.54	6.07	891.2	-6.54	5.63	896.5	-6.54	5.23	898.0	-6.54	4.86	896.0	-6.54	4.53	890.8
APR 4 SEP 9	-6.27	5.83	831.2	-6.27	5.41	841.9	-6.27	5.03	848.6	-6.27	4.69	851.5	-6.27	4.38	851.0
MAR 21 SEP 23	-6.00	5.58	761.1	-6.00	5.19	776.9	-6.00	4.83	788.7	-6.00	4.51	796.6	-6.00	4.22	800.7
MAR 7 OCT 8	-5.73	5.33	686.0	-5.73	4.96	706.3	-5.73	4.63	722.7	-5.73	4.33	734.9	-5.73	4.07	743.3
FEB 20 OCT 22	-5.46	5.09	611.4	-5.46	4.74	635.3	-5.46	4.43	655.4	-5.46	4.16	671.3	-5.46	3.92	683.2
FEB 7 NOV 5	-5.22	4.86	542.6	-5.22	4.54	569.1	-5.22	4.25	591.9	-5.22	4.00	610.5	-5.22	3.78	625.1
JAN 23 NOV 19	-5.02	4.68	485.9	-5.02	4.37	514.1	-5.02	4.10	538.7	-5.02	3.87	559.2	-5.02	3.66	575.7
JAN 10 DEC 3	-4.86	4.54	445.5	-4.86	4.25	474.7	-4.86	3.99	500.3	-4.86	3.77	522.0	-4.86	3.57	539.6
DEC 22	-4.77	4.46	421.8	-4.77	4.17	451.4	-4.77	3.93	477.6	-4.77	3.71	499.7	-4.77	3.52	517.9
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	271.691		.5169	276.340		.5258	279.638		.5320	281.591		.5358	282.312		.5371

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	20.2		30.4	17.7		33.8	15.4		36.8	13.3		39.4	11.3		41.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	4.58	939.3	-7.23	4.28	919.7	-7.23	4.01	900.0	-7.23	3.76	880.7	-7.23	3.55	861.9
JUN 1 JUL 12	-7.14	4.54	934.6	-7.14	4.24	916.3	-7.14	3.97	897.7	-7.14	3.74	879.4	-7.14	3.52	861.5
MAY 18 JUL 27	-6.98	4.47	925.1	-6.98	4.18	909.0	-6.98	3.92	892.3	-6.98	3.69	875.6	-6.98	3.48	859.2
MAY 3 AUG 10	-6.78	4.36	908.7	-6.78	4.09	895.5	-6.78	3.84	881.5	-6.78	3.62	867.2	-6.78	3.43	852.8
APR 19 AUG 25	-6.54	4.24	883.1	-6.54	3.98	873.5	-6.54	3.75	862.7	-6.54	3.55	851.2	-6.54	3.36	839.4
APR 4 SEP 9	-6.27	4.11	847.6	-6.27	3.87	842.0	-6.27	3.65	834.7	-6.27	3.46	826.4	-6.27	3.29	817.3
MAR 21 SEP 23	-6.00	3.97	801.6	-6.00	3.75	799.9	-6.00	3.55	796.2	-6.00	3.37	791.0	-6.00	3.21	784.8
MAR 7 OCT 8	-5.73	3.83	748.2	-5.73	3.63	750.1	-5.73	3.44	749.6	-5.73	3.28	747.6	-5.73	3.14	744.2
FEB 20 OCT 22	-5.46	3.70	691.4	-5.46	3.51	696.5	-5.46	3.35	699.0	-5.46	3.20	699.6	-5.46	3.07	698.6
FEB 7 NOV 5	-5.22	3.58	636.0	-5.22	3.41	642.6	-5.22	3.25	648.4	-5.22	3.12	651.1	-5.22	3.00	652.2
JAN 23 NOV 19	-5.02	3.48	588.4	-5.02	3.32	597.8	-5.02	3.18	604.4	-5.02	3.06	608.6	-5.02	2.95	611.2
JAN 10 DEC 3	-4.86	3.40	553.4	-4.86	3.25	563.9	-4.86	3.12	571.6	-4.86	3.01	576.9	-4.86	2.91	580.4
DEC 22	-4.77	3.36	532.4	-4.77	3.22	543.4	-4.77	3.09	551.7	-4.77	2.98	557.5	-4.77	2.88	561.6
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	281.982		.5365	280.810		.5343	279.010		.5308	276.773		.5266	274.233		.5218

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 36 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 35.6		ALPHA 7.1	THETA 35.2		ALPHA 13.9	THETA 34.3		ALPHA 20.3	THETA 33.1		ALPHA 26.3	THETA 31.7		ALPHA 31.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	6.75	1015.7	-7.23	6.26	1008.3	-7.23	5.79	996.9	-7.23	5.34	982.6	-7.23	4.92	966.2
JUN 1 JUL 12	-7.14	6.66	1000.7	-7.14	6.18	993.6	-7.14	5.71	982.7	-7.14	5.26	969.0	-7.14	4.85	953.3
MAY 18 JUL 27	-6.98	6.51	974.0	-6.98	6.03	967.4	-6.98	5.57	957.4	-6.98	5.13	944.6	-6.96	4.72	930.2
MAY 3 AUG 10	-6.78	6.30	934.0	-6.78	5.83	928.2	-6.78	5.37	919.4	-6.78	4.94	908.2	-6.78	4.55	895.2
APR 19 AUG 25	-6.54	6.06	880.5	-6.54	5.59	875.8	-6.54	5.15	868.4	-6.54	4.73	858.9	-6.54	4.34	847.8
APR 4 SEP 9	-6.27	5.80	815.7	-6.27	5.34	812.1	-6.27	4.90	806.2	-6.27	4.49	798.7	-6.27	4.12	789.7
MAR 21 SEP 23	-6.00	5.53	741.1	-6.00	5.07	738.5	-6.00	4.64	734.3	-6.00	4.25	728.7	-6.00	3.89	721.9
MAR 7 OCT 8	-5.73	5.26	662.0	-5.73	4.81	660.5	-5.73	4.39	657.8	-5.73	4.00	654.1	-5.73	3.65	649.3
FEB 20 OCT 22	-5.46	5.00	584.3	-5.46	4.55	583.6	-5.46	4.14	582.4	-5.46	3.77	580.3	-5.46	3.43	577.4
FEB 7 NOV 5	-5.22	4.76	513.2	-5.22	4.32	513.3	-5.22	3.91	513.1	-5.22	3.55	512.4	-5.22	3.22	511.0
JAN 23 NOV 19	-5.02	4.55	455.1	-5.02	4.12	455.8	-5.02	3.72	456.5	-5.02	3.37	456.7	-5.02	3.05	456.4
JAN 10 DEC 3	-4.86	4.40	414.1	-4.86	3.97	415.1	-4.86	3.58	416.3	-4.86	3.23	417.2	-4.86	2.92	417.6
DEC 22	-4.77	4.31	390.0	-4.77	3.88	391.2	-4.77	3.49	392.7	-4.77	3.15	394.0	-4.77	2.85	394.8
	YEAR 265.460		R.I. .5051	YEAR 264.401		R.I. .5030	YEAR 262.701		R.I. .4998	YEAR 260.442		R.I. .4955	YEAR 257.734		R.I. .4904

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 30.3		ALPHA 36.6	THETA 28.8		ALPHA 40.9	THETA 27.3		ALPHA 44.7	THETA 25.9		ALPHA 48.0	THETA 24.6		ALPHA 51.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.23	4.54	948.7	-7.23	4.20	930.7	-7.23	3.89	912.8	-7.23	3.61	895.3	-7.23	3.36	878.4
JUN 1 JUL 12	-7.14	4.47	936.5	-7.14	4.13	919.2	-7.14	3.82	901.9	-7.14	3.55	885.0	-7.14	3.31	868.6
MAY 18 JUL 27	-6.98	4.35	914.5	-6.98	4.02	898.3	-6.98	3.72	882.0	-6.98	3.45	866.1	-6.98	3.21	850.7
MAY 3 AUG 10	-6.78	4.19	881.1	-6.78	3.86	866.4	-6.78	3.57	851.7	-6.78	3.32	837.2	-6.78	3.09	823.1
APR 19 AUG 25	-6.54	3.99	835.7	-6.54	3.68	823.0	-6.54	3.40	810.1	-6.54	3.16	797.3	-6.54	2.94	784.8
APR 4 SEP 9	-6.27	3.78	779.7	-6.27	3.48	769.1	-6.27	3.22	758.3	-6.27	2.98	747.4	-6.27	2.77	736.7
MAR 21 SEP 23	-6.00	3.56	714.1	-6.00	3.27	705.8	-6.00	3.02	697.1	-6.00	2.80	688.2	-6.00	2.60	679.4
MAR 7 OCT 8	-5.73	3.34	643.7	-5.73	3.07	637.5	-5.73	2.83	630.8	-5.73	2.61	623.9	-5.73	2.43	616.9
FEB 20 OCT 22	-5.46	3.13	573.7	-5.46	2.87	569.3	-5.46	2.64	564.5	-5.46	2.44	559.3	-5.46	2.26	554.0
FEB 7 NOV 5	-5.22	2.94	508.8	-5.22	2.69	506.1	-5.22	2.47	502.8	-5.22	2.28	499.1	-5.22	2.11	495.1
JAN 23 NOV 19	-5.02	2.77	455.4	-5.02	2.53	453.8	-5.02	2.32	451.7	-5.02	2.14	449.1	-5.02	1.98	446.2
JAN 10 DEC 3	-4.86	2.65	417.4	-4.86	2.42	416.5	-4.86	2.22	415.1	-4.86	2.04	413.2	-4.86	1.89	411.0
DEC 22	-4.77	2.58	394.9	-4.77	2.35	394.5	-4.77	2.16	393.5	-4.77	1.98	392.0	-4.77	1.83	390.2
	YEAR 254.695		R.I. .4846	YEAR 251.437		R.I. .4784	YEAR 248.070		R.I. .4720	YEAR 244.685		R.I. .4655	YEAR 241.320		R.I. .4591

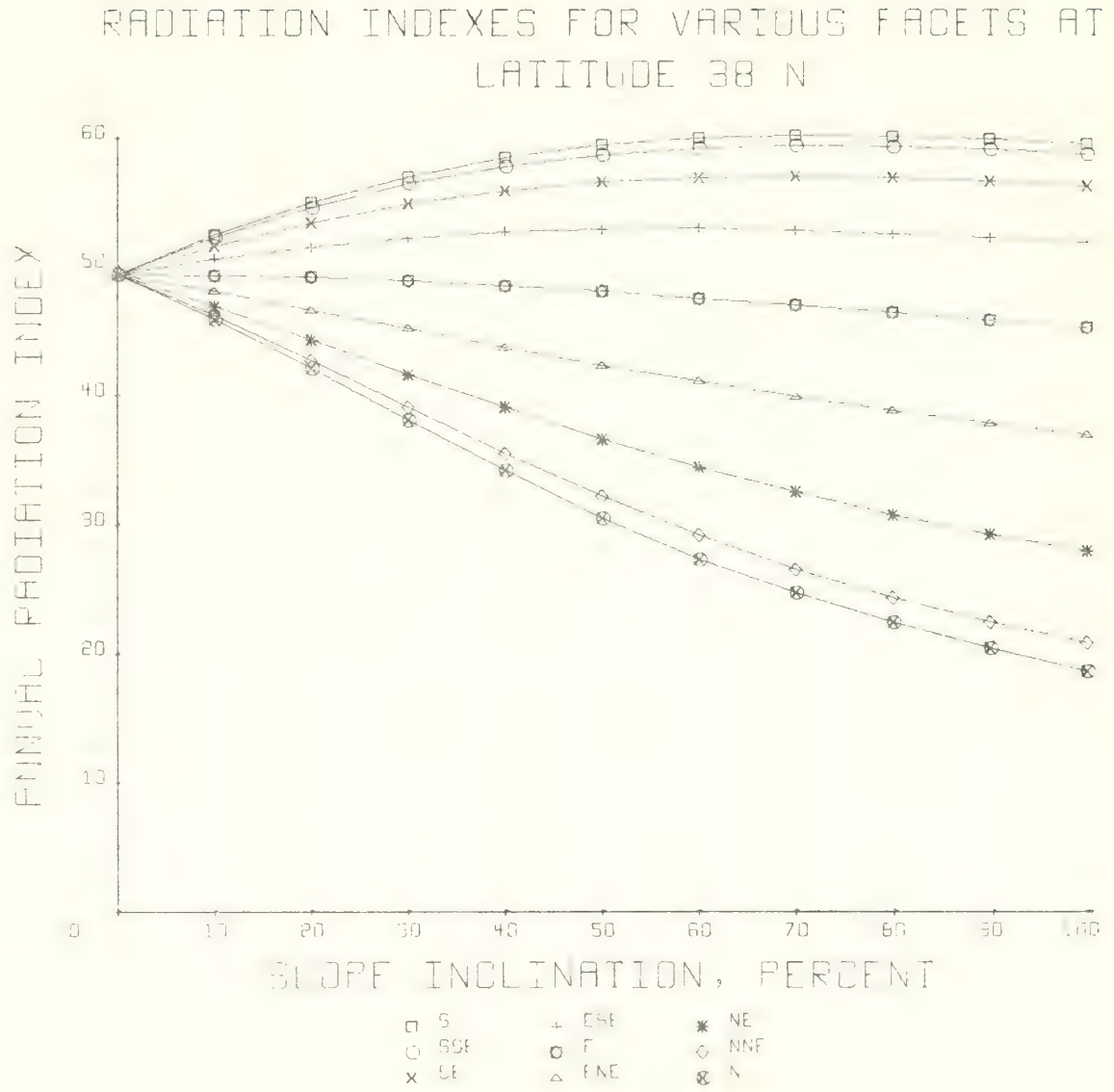
NOTE - FOR ASPECTS WITH WEST COMPONENTS. THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 38 N

		SR	SS	LY
JUN 22		-7.32	7.32	1020.9
JUN 1	JUL 12	-7.22	7.22	1004.1
MAY 18	JUL 27	-7.06	7.06	974.3
MAY 3	AUG 10	-6.84	6.84	930.2
APR 19	AUG 25	-6.58	6.58	872.0
APR 4	SEP 9	-6.29	6.29	802.1
MAR 21	SEP 23	-6.00	6.00	722.7
MAR 7	OCT 8	-5.71	5.71	639.4
FEB 20	OCT 22	-5.42	5.42	558.4
FEB 7	NOV 5	-5.16	5.16	485.0
JAN 23	NOV 19	-4.94	4.94	425.5
JAN 10	DEC 3	-4.78	4.78	383.6
DEC 22		-4.68	4.68	359.2

YEAR	R.I.
259.861	.4944



LATITUDE 38 N
ASPECT N --

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 43.7		ALPHA 0.0	THETA 49.3		ALPHA 0.0	THETA 54.7		ALPHA 0.0	THETA 59.8		ALPHA 0.0	THETA 64.6		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	7.32	1022.2	-7.32	7.32	1013.5	-7.32	7.32	996.1	-7.32	7.32	971.5	-7.32	7.32	941.5
JUN 1 JUL 12	-7.22	7.22	1000.5	-7.22	7.22	987.3	-7.22	7.22	965.8	-7.22	7.22	937.5	-7.22	7.22	904.3
MAY 18 JUL 27	-7.06	7.06	962.7	-7.06	7.06	942.0	-7.06	7.06	913.7	-7.06	7.06	879.3	-7.06	7.06	841.0
MAY 3 AUG 10	-6.84	6.84	907.7	-6.84	6.84	877.0	-6.84	6.84	839.5	-6.84	6.84	797.1	-6.84	6.84	751.9
APR 19 AUG 25	-6.58	6.58	837.0	-6.58	6.58	794.7	-6.58	6.58	746.8	-6.58	6.58	695.4	-6.58	6.58	642.3
APR 4 SEP 9	-6.29	6.29	754.3	-6.29	6.29	700.2	-6.29	6.29	641.9	-6.29	6.29	581.4	-6.29	6.29	520.7
MAR 21 SEP 24	-6.00	6.00	662.8	-6.00	6.00	597.8	-6.00	6.00	530.0	-6.00	6.00	461.3	-6.00	6.00	393.9
MAR 7 OCT 8	-5.64	5.64	569.4	-5.56	5.56	495.6	-5.47	5.47	420.5	-5.35	5.35	346.3	-5.20	5.20	274.9
FEB 20 OCT 22	-5.29	5.29	480.9	-5.14	5.14	401.2	-4.95	4.95	322.2	-4.71	4.71	246.1	-4.40	4.40	175.4
FEB 7 NOV 5	-4.97	4.97	402.6	-4.74	4.74	319.9	-4.45	4.45	240.0	-4.09	4.09	165.5	-3.61	3.61	99.4
JAN 23 NOV 19	-4.69	4.69	340.5	-4.39	4.39	257.0	-4.02	4.02	178.4	-3.53	3.53	107.8	-2.83	2.83	49.0
JAN 10 DEC 3	-4.49	4.49	297.6	-4.13	4.13	214.5	-3.68	3.68	138.0	-3.08	3.08	71.9	-2.13	2.13	21.2
DEC 22	-4.36	4.36	273.0	-3.97	3.97	190.5	-3.47	3.47	115.8	-2.78	2.78	53.1	-1.59	1.59	8.9
	YEAR 241.375		R.I. .4592	YEAR 221.330		R.I. .4211	YEAR 200.586		R.I. .3816	YEAR 180.017		R.I. .3425	YEAR 160.609		R.I. .3056

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 69.0		ALPHA 0.0	THETA 73.0		ALPHA 0.0	THETA 76.7		ALPHA 0.0	THETA 80.0		ALPHA 0.0	THETA 83.0		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	7.32	908.1	-7.32	7.32	872.7	-7.32	7.32	836.8	-7.32	7.32	801.4	-7.32	7.32	766.8
JUN 1 JUL 12	-7.22	7.22	868.2	-7.22	7.22	830.5	-7.22	7.22	792.7	-7.22	7.22	755.7	-7.22	7.22	719.8
MAY 18 JUL 27	-7.06	7.06	800.4	-7.06	7.06	759.0	-7.06	7.06	718.1	-7.06	7.06	678.7	-7.06	7.06	640.7
MAY 3 AUG 10	-6.84	6.84	705.4	-6.84	6.84	659.2	-6.84	6.84	614.4	-6.84	6.84	571.6	-6.84	6.84	531.0
APR 19 AUG 25	-6.58	6.58	589.4	-6.58	6.58	537.9	-6.58	6.58	488.7	-6.58	6.58	442.5	-6.58	6.58	399.1
APR 4 SEP 9	-6.29	6.29	461.5	-6.29	6.29	404.8	-6.29	6.29	351.5	-6.29	6.29	302.0	-6.29	6.29	256.1
MAR 21 SEP 23	-6.00	6.00	329.2	-6.00	6.00	268.1	-6.00	6.00	211.5	-6.00	6.00	159.5	-6.00	6.00	111.7
MAR 7 OCT 8	-5.01	5.01	208.1	-4.75	4.75	146.8	-4.36	4.36	92.1	-3.74	3.74	45.3	-2.44	2.44	9.3
FEB 20 OCT 22	-3.99	3.99	111.9	-3.39	3.39	57.7	-2.37	2.37	16.1	0.00	0.00	0.0	0.00	0.00	0.0
FEB 7 NOV 5	-2.90	2.90	44.6	-1.61	1.61	6.5	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	-1.61	1.61	7.8	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 143.868		R.I. .2737	YEAR 129.825		R.I. .2470	YEAR 117.750		R.I. .2240	YEAR 107.266		R.I. .2041	YEAR 98.011		R.I. .1865

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 38 N
ASPECT S -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 32.3		ALPHA 0.0	THETA 26.7		ALPHA 0.0	THETA 21.3		ALPHA 0.0	THETA 16.2		ALPHA 0.0	THETA 11.4		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.06	7.06	1011.1	-6.84	6.84	994.2	-6.65	6.65	971.1	-6.48	6.48	942.9	-6.34	6.34	911.0
JUN 1 JUL 12	-6.98	6.98	999.1	-6.78	6.78	986.7	-6.60	6.60	967.7	-6.45	6.45	943.2	-6.31	6.31	914.6
MAY 18 JUL 27	-6.85	6.85	977.3	-6.68	6.68	972.5	-6.52	6.52	960.5	-6.39	6.39	942.3	-6.27	6.27	919.4
MAY 3 AUG 10	-6.68	6.68	944.1	-6.54	6.54	949.7	-6.42	6.42	947.4	-6.31	6.31	938.1	-6.22	6.22	923.3
APR 19 AUG 25	-6.47	6.47	898.6	-6.37	6.37	916.5	-6.29	6.29	925.9	-6.21	6.21	927.7	-6.15	6.15	922.9
APR 4 SEP 9	-6.24	6.24	842.1	-6.19	6.19	873.2	-6.15	6.15	895.3	-6.11	6.11	909.2	-6.08	6.08	915.6
MAR 21 SEP 23	-6.00	6.00	775.3	-6.00	6.00	819.4	-6.00	6.00	854.5	-6.00	6.00	880.7	-6.00	6.00	898.9
MAR 7 OCT 8	-5.71	5.71	703.1	-5.71	5.71	758.8	-5.71	5.71	805.5	-5.71	5.71	843.1	-5.71	5.71	872.3
FEB 20 OCT 22	-5.42	5.42	630.7	-5.42	5.42	695.5	-5.42	5.42	751.6	-5.42	5.42	798.5	-5.42	5.42	836.7
FEB 7 NOV 5	-5.16	5.16	563.3	-5.16	5.16	634.6	-5.16	5.16	697.5	-5.16	5.16	751.4	-5.16	5.16	796.4
JAN 23 NOV 19	-4.94	4.94	507.5	-4.94	4.94	582.9	-4.94	4.94	650.2	-4.94	4.94	708.6	-4.94	4.94	758.2
JAN 10 DEC 3	-4.78	4.78	467.5	-4.78	4.78	545.1	-4.78	4.78	614.8	-4.78	4.78	675.9	-4.78	4.78	728.2
DEC 22	-4.68	4.68	443.8	-4.68	4.68	522.5	-4.68	4.68	593.4	-4.68	4.68	655.7	-4.68	4.68	709.3
	YEAR 276.068		R.I. .5252	YEAR 289.517		R.I. .5508	YEAR 300.026		R.I. .5708	YEAR 307.686		R.I. .5854	YEAR 312.761		R.I. .5951

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 7.0		ALPHA 0.0	THETA 3.0		ALPHA 0.0	THETA -0.7		ALPHA 0.0	THETA -4.0		ALPHA 0.0	THETA -7.0		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.21	6.21	877.0	-6.09	6.09	842.1	-5.98	5.98	807.4	-5.88	5.88	773.7	-5.80	5.80	741.2
JUN 1 JUL 12	-6.19	6.19	883.5	-6.08	6.08	851.1	-5.98	5.98	818.6	-5.89	5.89	786.7	-5.81	5.81	755.9
MAY 18 JUL 27	-6.17	6.17	893.3	-6.07	6.07	865.3	-5.98	5.98	836.6	-5.91	5.91	808.0	-5.84	5.84	780.0
MAY 3 AUG 10	-6.13	6.13	904.5	-6.06	6.06	882.8	-5.99	5.99	859.6	-5.93	5.93	835.9	-5.87	5.87	812.0
APR 19 AUG 25	-6.09	6.09	913.1	-6.04	6.04	899.5	-5.99	5.99	883.4	-5.95	5.95	865.9	-5.91	5.91	847.5
APR 4 SEP 9	-6.05	6.05	916.0	-6.02	6.02	911.7	-6.00	6.00	903.9	-5.97	5.97	893.7	-5.95	5.95	881.8
MAR 21 SEP 23	-6.00	6.00	910.2	-6.00	6.00	915.8	-6.00	6.00	917.0	-6.00	6.00	914.9	-6.00	6.00	910.3
MAR 7 OCT 8	-5.71	5.71	893.9	-5.71	5.71	909.0	-5.71	5.71	918.9	-5.71	5.71	924.6	-5.71	5.71	927.0
FEB 20 OCT 22	-5.42	5.42	866.8	-5.42	5.42	890.0	-5.42	5.42	907.1	-5.42	5.42	919.5	-5.42	5.42	928.1
FEB 7 NOV 5	-5.16	5.16	833.0	-5.16	5.16	862.3	-5.16	5.16	885.2	-5.16	5.16	902.8	-5.16	5.16	916.2
JAN 23 NOV 19	-4.94	4.94	799.3	-4.94	4.94	832.8	-4.94	4.94	859.8	-4.94	4.94	881.1	-4.94	4.94	897.9
JAN 10 DEC 3	-4.78	4.78	771.9	-4.78	4.78	806.1	-4.78	4.78	837.4	-4.78	4.78	861.1	-4.78	4.78	880.0
DEC 22	-4.68	4.68	754.4	-4.68	4.68	791.9	-4.68	4.68	822.5	-4.68	4.68	847.3	-4.68	4.68	867.5
	YEAR 315.618		R.I. .6005	YEAR 316.679		R.I. .6025	YEAR 316.344		R.I. .6019	YEAR 314.975		R.I. .5993	YEAR 312.855		R.I. .5952

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 38 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 43.2		ALPHA 3.0	THETA 48.3		ALPHA 6.5	THETA 53.0		ALPHA 10.5	THETA 57.4		ALPHA 15.3	THETA 61.2		ALPHA 20.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	7.32	1021.7	-7.32	7.32	1012.6	-7.32	7.32	994.7	-7.32	7.32	969.7	-7.32	7.32	939.4
JUN 1 JUL 12	-7.22	7.22	1000.4	-7.22	7.22	987.1	-7.22	7.22	965.5	-7.22	7.22	937.1	-7.22	7.22	903.8
MAY 18 JUL 27	-7.06	7.06	963.2	-7.06	7.06	943.0	-7.06	7.06	915.1	-7.06	7.06	881.3	-7.06	7.06	843.3
MAY 3 AUG 10	-6.84	6.81	909.1	-6.84	6.78	879.7	-6.84	6.75	843.5	-6.84	6.70	802.3	-6.84	6.64	758.2
APR 19 AUG 25	-6.58	6.50	839.4	-6.58	6.40	799.6	-6.58	6.29	754.3	-6.58	6.15	705.5	-6.58	5.98	655.2
APR 4 SEP 9	-6.29	6.15	757.9	-6.29	5.99	707.7	-6.29	5.80	653.8	-6.29	5.57	598.1	-6.29	5.30	542.8
MAR 21 SEP 23	-6.00	5.80	667.6	-6.00	5.57	608.2	-6.00	5.30	547.0	-6.00	4.98	486.0	-6.00	4.61	427.5
MAR 7 OCT 8	-5.71	5.45	575.2	-5.71	5.14	508.5	-5.71	4.80	442.0	-5.71	4.39	377.9	-5.71	3.92	318.4
FEB 20 OCT 22	-5.42	5.10	487.4	-5.42	4.73	415.7	-5.42	4.31	346.2	-5.42	3.81	281.2	-5.42	3.24	222.9
FEB 7 NOV 5	-5.16	4.79	409.5	-5.16	4.35	335.1	-5.16	3.85	264.7	-5.16	3.26	200.8	-5.16	2.58	145.5
JAN 23 NOV 19	-4.92	4.52	347.6	-4.89	4.02	272.2	-4.85	3.45	202.5	-4.80	2.77	141.0	-4.74	1.97	89.7
JAN 10 DEC 3	-4.71	4.31	304.7	-4.64	3.77	229.5	-4.54	3.14	161.3	-4.42	2.38	102.6	-4.24	1.47	55.6
DEC 22	-4.59	4.19	280.0	-4.49	3.62	205.3	-4.35	2.95	138.4	-4.17	2.13	81.9	-3.90	1.13	38.2
	YEAR 242.825		R.I. .4620	YEAR 224.460		R.I. .4271	YEAR 205.587		R.I. .3911	YEAR 186.992		R.I. .3558	YEAR 169.416		R.I. .3223

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 64.5		ALPHA 27.2	THETA 67.2		ALPHA 34.5	THETA 69.3		ALPHA 42.6	THETA 70.8		ALPHA 51.3	THETA 71.8		ALPHA 60.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	7.32	905.6	-7.32	7.32	869.9	-7.32	7.32	833.8	-7.32	7.32	798.1	-7.32	7.32	763.4
JUN 1 JUL 12	-7.22	7.22	867.6	-7.22	7.22	829.9	-7.22	7.22	792.0	-7.22	7.22	755.0	-7.22	7.22	719.1
MAY 18 JUL 27	-7.06	7.06	803.0	-7.06	7.06	762.0	-7.06	7.06	721.4	-7.06	7.06	682.1	-7.06	7.06	644.4
MAY 3 AUG 10	-6.84	6.57	712.8	-6.84	6.47	667.6	-6.84	6.33	623.7	-6.84	6.14	582.0	-6.84	5.87	542.7
APR 19 AUG 25	-6.58	5.78	605.2	-6.58	5.52	556.8	-6.58	5.21	511.2	-6.58	4.83	469.3	-6.58	4.39	431.0
APR 4 SEP 9	-6.29	4.98	489.6	-6.29	4.60	439.8	-6.29	4.17	394.5	-6.29	3.68	354.3	-6.29	3.15	319.1
MAR 21 SEP 23	-6.00	4.19	373.1	-6.00	3.70	324.0	-6.00	3.16	281.1	-6.00	2.58	244.6	-6.00	1.99	214.1
MAR 7 OCT 8	-5.71	3.39	265.0	-5.71	2.79	218.8	-5.71	2.15	180.3	-5.71	1.48	149.2	-5.71	.82	124.7
FEB 20 OCT 22	-5.42	2.60	172.6	-5.42	1.88	131.2	-5.42	1.11	98.7	-5.42	.33	74.4	-5.42	-.41	56.9
FEB 7 NOV 5	-5.16	1.80	100.0	-5.16	.93	64.9	-5.16	-.02	39.8	-5.16	-.98	23.4	-5.16	-1.89	13.5
JAN 23 NOV 19	-4.66	1.03	49.9	-4.53	-.07	22.0	-4.28	-1.40	5.6	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	-3.97	.34	21.8	-3.39	-1.21	2.6	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-3.44	-.19	9.4	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 153.477		R.I. .2920	YEAR 139.671		R.I. .2657	YEAR 128.038		R.I. .2436	YEAR 118.034		R.I. .2246	YEAR 109.340		R.I. .2080

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 38 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	32.7		2.6	27.4		4.9	22.4		6.8	17.5		8.6	13.0		10.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.25	6.91	1012.0	-7.19	6.55	996.9	-7.14	6.23	976.2	-7.10	5.95	950.9	-7.06	5.71	922.1
JUN 1 JUL 12	-7.17	6.83	999.7	-7.13	6.48	986.8	-7.09	6.18	972.0	-7.06	5.92	950.2	-7.03	5.68	924.6
MAY 18 JUL 27	-7.04	6.69	977.4	-7.02	6.38	973.6	-7.01	6.10	963.4	-7.00	5.85	947.7	-6.98	5.64	927.6
MAY 3 AUG 10	-6.84	6.51	943.4	-6.84	6.23	949.4	-6.84	5.98	948.4	-6.84	5.77	941.1	-6.84	5.57	928.8
APR 19 AUG 25	-6.58	6.30	896.9	-6.58	6.06	914.3	-6.58	5.85	924.2	-6.58	5.66	927.2	-6.58	5.50	924.1
APR 4 SEP 9	-6.29	6.07	839.3	-6.29	5.87	868.7	-6.29	5.70	890.1	-6.29	5.55	903.9	-6.29	5.41	910.9
MAR 21 SEP 23	-6.00	5.83	771.4	-6.00	5.68	812.5	-6.00	5.54	845.1	-6.00	5.43	869.6	-6.00	5.33	886.6
MAR 7 OCT 8	-5.71	5.58	698.2	-5.71	5.48	749.5	-5.71	5.39	792.2	-5.71	5.31	826.5	-5.71	5.24	852.8
FEB 20 OCT 22	-5.42	5.35	625.1	-5.42	5.29	684.5	-5.42	5.24	735.5	-5.42	5.20	778.0	-5.42	5.16	812.1
FEB 7 NOV 5	-5.16	5.14	557.2	-5.16	5.12	622.5	-5.16	5.11	679.8	-5.16	5.09	728.5	-5.16	5.08	768.9
JAN 23 NOV 19	-4.94	4.94	501.1	-4.94	4.94	570.3	-4.94	4.94	631.7	-4.94	4.94	684.8	-4.94	4.94	729.4
JAN 10 DEC 3	-4.78	4.78	460.9	-4.78	4.78	532.2	-4.78	4.78	596.0	-4.78	4.78	651.6	-4.78	4.78	698.9
DEC 22	-4.68	4.68	437.3	-4.68	4.68	509.5	-4.68	4.68	574.4	-4.68	4.68	631.2	-4.68	4.68	679.8
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	274.863		.5230	287.349		.5467	297.120		.5653	304.243		.5788	308.951		.5878

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	8.8		11.5	5.0		12.7	1.5		13.8	-1.7		14.8	-4.6		15.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.02	5.49	891.3	-6.99	5.30	859.6	-6.97	5.12	828.0	-6.94	4.96	797.3	-6.92	4.82	767.6
JUN 1 JUL 12	-7.01	5.47	896.6	-6.98	5.29	867.4	-6.96	5.12	838.0	-6.94	4.97	809.1	-6.93	4.83	781.0
MAY 18 JUL 27	-6.97	5.44	904.5	-6.97	5.27	879.5	-6.96	5.11	853.8	-6.95	4.97	828.1	-6.94	4.84	802.9
MAY 3 AUG 10	-6.84	5.40	912.6	-6.84	5.24	893.8	-6.84	5.11	873.4	-6.84	4.98	852.4	-6.84	4.87	831.3
APR 19 AUG 25	-6.58	5.35	916.3	-6.58	5.22	905.0	-6.58	5.10	891.2	-6.58	4.99	876.0	-6.58	4.89	860.0
APR 4 SEP 9	-6.29	5.29	912.2	-6.29	5.18	909.1	-6.29	5.09	902.7	-6.29	5.00	893.9	-6.29	4.92	883.5
MAR 21 SEP 23	-6.00	5.23	897.2	-6.00	5.15	902.4	-6.00	5.08	903.5	-6.00	5.01	901.4	-6.00	4.95	897.0
MAR 7 OCT 8	-5.71	5.18	871.9	-5.71	5.12	885.1	-5.71	5.07	893.3	-5.71	5.02	897.7	-5.71	4.98	899.1
FEB 20 OCT 22	-5.42	5.12	838.7	-5.42	5.09	858.8	-5.42	5.06	873.4	-5.42	5.03	883.5	-5.42	5.01	890.2
FEB 7 NOV 5	-5.16	5.07	801.4	-5.16	5.06	827.0	-5.16	5.05	846.8	-5.16	5.04	861.7	-5.16	5.03	872.8
JAN 23 NOV 19	-4.94	4.94	766.2	-4.94	4.94	796.0	-4.94	4.94	819.6	-4.94	4.94	838.1	-4.94	4.94	852.5
JAN 10 DEC 3	-4.78	4.78	736.2	-4.78	4.78	770.5	-4.78	4.78	796.5	-4.78	4.78	817.2	-4.78	4.78	833.7
DEC 22	-4.68	4.68	720.4	-4.68	4.68	754.0	-4.68	4.68	781.3	-4.68	4.68	803.2	-4.68	4.68	820.8
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	311.582		.5928	312.530		.5946	312.167		.5939	310.635		.5914	306.800		.5875

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 71.9		ALPHA 5.4	THETA 45.9		ALPHA 11.8	THETA 48.0		ALPHA 17.9	THETA 51.1		ALPHA 24.1	THETA 53.1		ALPHA 31.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	7.62	1020.4	-7.32	6.99	1010.9	-7.32	6.78	993.1	-7.32	6.53	969.0	-7.32	6.24	940.6
JUN 1 JUL 12	-7.22	7.47	1000.4	-7.22	6.85	987.1	-7.22	6.62	967.5	-7.22	6.35	941.0	-7.22	6.05	911.1
MAY 18 JUL 27	-7.06	6.86	969.1	-7.06	6.63	941.0	-7.06	6.37	923.2	-7.06	6.07	894.4	-7.06	5.74	862.1
MAY 3 AUG 10	-6.84	6.60	918.7	-6.84	6.34	889.7	-6.84	6.04	860.4	-6.84	5.70	827.4	-6.84	5.31	792.0
APR 19 AUG 25	-6.58	6.30	868.0	-6.58	5.99	815.9	-6.58	5.65	781.6	-6.58	5.27	744.0	-6.58	4.87	706.8
APR 4 SEP 9	-6.29	5.98	768.1	-6.29	5.62	736.4	-6.29	5.24	690.2	-6.29	4.82	649.7	-6.29	4.38	610.5
MAR 21 SEP 23	-6.00	5.64	680.7	-6.00	5.24	636.6	-6.00	4.81	592.1	-6.00	4.35	549.2	-6.00	3.88	509.1
MAR 7 OCT 8	-5.71	5.30	590.1	-5.71	4.86	541.8	-5.71	4.38	494.3	-5.71	3.86	450.0	-5.71	3.38	410.2
FEB 20 OCT 22	-5.42	4.97	504.8	-5.42	4.48	452.5	-5.42	3.97	403.4	-5.42	3.43	359.2	-5.42	2.89	320.6
FEB 7 NOV 5	-5.16	4.67	428.2	-5.16	4.14	374.1	-5.16	3.58	324.9	-5.16	3.00	281.7	-5.16	2.43	245.2
JAN 23 NOV 19	-4.94	4.41	366.9	-4.94	3.85	312.3	-4.94	3.25	263.8	-4.94	2.63	222.2	-4.94	2.02	188.1
JAN 10 DEC 3	-4.78	4.22	324.3	-4.78	3.62	269.9	-4.78	2.99	222.3	-4.78	2.35	182.3	-4.78	1.71	150.2
DEC 22	-4.68	4.11	299.7	-4.68	3.49	245.6	-4.68	2.84	198.7	-4.68	2.17	159.9	-4.68	1.52	129.2
	YEAR 246.891		R.I. .4697	YEAR 233.083		R.I. .4435	YEAR 219.095		R.I. .4168	YEAR 205.497		R.I. .3910	YEAR 192.750		R.I. .3667

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 54.5		ALPHA 38.9	THETA 55.5		ALPHA 45.7	THETA 56.0		ALPHA 52.2	THETA 56.1		ALPHA 58.1	THETA 56.0		ALPHA 63.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	5.92	909.8	-7.32	5.57	878.3	-7.32	5.20	847.6	-7.32	4.82	818.0	-7.32	4.45	790.5
JUN 1 JUL 12	-7.22	5.71	879.9	-7.22	5.35	847.9	-7.22	4.97	816.8	-7.22	4.59	787.6	-7.22	4.22	760.4
MAY 18 JUL 27	-7.06	5.38	829.2	-7.06	5.00	796.5	-7.06	4.61	765.3	-7.06	4.23	736.4	-7.06	3.86	709.7
MAY 3 AUG 10	-6.84	4.95	758.2	-6.84	4.55	724.9	-6.84	4.15	693.8	-6.84	3.76	665.5	-6.84	3.40	639.8
APR 19 AUG 25	-6.58	4.46	671.0	-6.58	4.04	637.5	-6.58	3.65	607.0	-6.58	3.24	579.8	-6.58	2.88	555.5
APR 4 SEP 9	-6.29	3.94	574.2	-6.29	3.50	541.2	-6.29	3.08	511.9	-6.29	2.69	486.3	-6.29	2.33	463.9
MAR 21 SEP 23	-6.00	3.41	473.1	-6.00	2.95	441.4	-6.00	2.52	414.0	-6.00	2.13	390.6	-6.00	1.77	370.6
MAR 7 OCT 8	-5.71	2.88	375.5	-5.71	2.40	345.8	-5.71	1.96	320.9	-5.71	1.56	300.2	-5.71	1.21	282.8
FEB 20 OCT 22	-5.42	2.36	288.1	-5.42	1.87	261.1	-5.42	1.42	239.1	-5.42	1.01	221.3	-5.42	.66	206.7
FEB 7 NOV 5	-5.16	1.87	215.3	-5.16	1.36	191.3	-5.16	.90	172.3	-5.16	.49	157.4	-5.16	.14	145.5
JAN 23 NOV 19	-4.94	1.44	160.9	-4.94	.91	139.7	-4.94	.44	123.5	-4.94	.03	111.1	-4.94	-.33	101.5
JAN 10 DEC 3	-4.78	1.11	125.3	-4.78	.56	106.4	-4.78	.08	92.3	-4.78	-.34	81.8	-4.78	-.68	73.8
DEC 22	-4.68	.90	105.7	-4.68	.34	88.3	-4.68	-.15	75.5	-4.68	-.57	66.1	-4.68	-.91	59.2
	YEAR 161.150		R.I. .3447	YEAR 170.808		R.I. .3250	YEAR 161.734		R.I. .3077	YEAR 153.855		R.I. .2927	YEAR 146.984		R.I. .2797

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 56 N
ASPECT [illegible] - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 33.4		ALPHA 4.9	THETA 29.6		ALPHA 9.2	THETA 25.4		ALPHA 13.0	THETA 21.4		ALPHA 16.4	THETA 17.5		ALPHA 20.4
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	6.81	1014.3	-7.32	6.34	1003.3	-7.32	5.93	988.1	-7.32	5.56	969.3	-7.32	5.24	947.7
JUN 1 JUL 12	-7.22	6.74	1000.9	-7.22	6.27	993.2	-7.22	5.87	981.1	-7.22	5.51	965.1	-7.22	5.20	946.1
MAY 18 JUL 27	-7.06	6.58	976.9	-7.06	6.15	974.7	-7.06	5.77	967.8	-7.06	5.43	956.6	-7.06	5.13	941.8
MAY 3 AUG 10	-6.84	6.39	940.5	-6.84	6.00	945.9	-6.84	5.64	946.0	-6.84	5.33	941.3	-6.84	5.05	932.4
APR 19 AUG 25	-6.58	6.17	895.7	-6.58	5.81	905.8	-6.58	5.48	913.8	-6.58	5.20	916.7	-6.58	4.94	914.9
APR 4 SEP 9	-6.29	5.93	830.7	-6.29	5.60	854.9	-6.29	5.31	871.1	-6.29	5.06	882.7	-6.29	4.83	887.9
MAR 21 SEP 23	-6.00	5.83	760.7	-6.00	5.49	792.1	-6.00	5.13	817.6	-6.00	4.91	836.6	-6.00	4.71	849.7
MAR 7 OCT 8	-5.71	5.42	684.3	-5.71	5.17	724.1	-5.71	4.93	757.0	-5.71	4.76	783.1	-5.71	4.59	802.9
FEB 20 OCT 22	-5.42	5.16	609.1	-5.42	4.97	655.0	-5.42	4.78	693.4	-5.42	4.62	725.9	-5.42	4.46	751.3
FEB 7 NOV 2	-5.16	4.96	540.2	-5.16	4.78	590.8	-5.16	4.62	633.3	-5.16	4.49	669.7	-5.16	4.37	699.3
JAN 23 NOV 17	-4.94	4.77	482.2	-4.94	4.62	535.7	-4.94	4.49	581.6	-4.94	4.38	621.2	-4.94	4.28	653.6
JAN 10 DEC 1	-4.78	4.63	441.4	-4.78	4.50	496.6	-4.78	4.40	548.3	-4.78	4.30	585.4	-4.78	4.22	619.6
DEC 23	-4.68	4.55	418.1	-4.68	4.43	473.4	-4.68	4.34	521.9	-4.68	4.25	563.8	-4.68	4.18	599.1
	YEAR 271.366		R.I. .5153	YEAR 281.020		R.I. .5347	YEAR 288.548		R.I. .5490	YEAR 293.478		R.I. .5593	YEAR 297.473		R.I. .5666

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 14.1		ALPHA 24.0	THETA 10.6		ALPHA 27.9	THETA 7.8		ALPHA 26.2	THETA 4.9		ALPHA 28.3	THETA 2.4		ALPHA 30.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
[illegible]	[illegible]			-7.32	4.83	900.2	-7.32	4.46	875.2	-7.32	4.25	851.6	-7.32	4.07	828.4
[illegible]	[illegible]			-7.22	4.66	[illegible]	-7.22	4.44	880.1	-7.22	4.24	857.7	-7.22	4.06	835.7
[illegible]	[illegible]			-7.06	4.41	[illegible]	-7.06	4.18	865.7	-7.06	4.02	850.2	-7.06	4.05	840.4
[illegible]	[illegible]			-6.84	4.28	876.2	-6.84	4.38	890.6	-6.84	4.20	874.3	-6.84	4.03	857.1
[illegible]	[illegible]			-6.58	4.13	900.6	-6.58	4.33	910.0	-6.58	4.17	896.0	-6.58	4.03	885.2
[illegible]	[illegible]			-6.29	3.97	886.9	-6.29	4.19	901.2	-6.29	4.14	893.9	-6.29	4.[illegible]	886.4
[illegible]	[illegible]			[illegible]			-6.00	4.04	901.7	-6.00	4.11	899.0	-6.00	4.00	894.5
[illegible]	[illegible]			-5.71	3.82	878.2	-5.71	3.98	891.7	[illegible]			-5.71	3.94	[illegible]
[illegible]	[illegible]			[illegible]			-5.42	3.78	[illegible]	-5.42	3.90	881.6	-5.42	3.91	[illegible]
[illegible]	[illegible]			[illegible]			-5.16	3.65	[illegible]	-5.16	3.80	[illegible]	-5.16	3.85	[illegible]
[illegible]	[illegible]			[illegible]			[illegible]			-4.94	3.70	[illegible]	-4.94	3.78	[illegible]
[illegible]	[illegible]			[illegible]			[illegible]			[illegible]			-4.78	3.69	[illegible]
[illegible]	[illegible]			[illegible]			[illegible]			[illegible]			[illegible]		[illegible]
	YEAR [illegible]		R.I. [illegible]	YEAR [illegible]		R.I. [illegible]	YEAR [illegible]		R.I. [illegible]	YEAR [illegible]		R.I. [illegible]	YEAR [illegible]		R.I. [illegible]

SLOPE

		60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
		THETA 43.1		ALPHA 40.6	THETA 42.6		ALPHA 46.1	THETA 42.0		ALPHA 51.0	THETA 41.3		ALPHA 55.3	THETA 40.4		ALPHA 59.1
		SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
	JUN 22	-7.32	4.89	936.0	-7.32	4.50	914.0	-7.32	4.14	892.5	-7.32	3.81	872.2	-7.32	3.51	853.0
JUN 1	JUL 12	-7.22	4.77	914.4	-7.22	4.38	892.5	-7.22	4.02	871.4	-7.22	3.70	851.4	-7.22	3.40	832.5
MAY 18	JUL 27	-7.06	4.57	877.1	-7.06	4.18	855.5	-7.06	3.83	834.8	-7.06	3.51	815.4	-7.06	3.22	797.2
MAY 3	AUG 10	-6.84	4.30	823.2	-6.84	3.92	802.2	-6.84	3.57	782.3	-6.84	3.26	763.7	-6.84	2.97	746.5
APR 19	AUG 25	-6.58	3.99	754.7	-6.58	3.61	734.5	-6.58	3.27	715.6	-6.58	2.96	698.2	-6.58	2.69	682.2
APR 4	SEP 9	-6.29	3.65	675.6	-6.29	3.28	656.5	-6.29	2.94	638.9	-6.29	2.65	623.0	-6.29	2.38	608.4
MAR 21	SEP 23	-6.00	3.29	589.2	-6.00	2.93	571.4	-6.00	2.60	555.4	-6.00	2.31	541.1	-6.00	2.06	528.1
MAR 7	OCT 8	-5.71	2.94	501.9	-5.71	2.58	485.7	-5.71	2.26	471.4	-5.71	1.98	458.8	-5.71	1.74	447.6
FEB 20	OCT 22	-5.42	2.60	420.0	-5.42	2.25	405.4	-5.42	1.94	392.9	-5.42	1.67	382.0	-5.42	1.43	372.4
FEB 7	NOV 5	-5.16	2.28	348.2	-5.16	1.94	335.3	-5.16	1.63	324.4	-5.16	1.37	315.0	-5.16	1.14	306.9
JAN 23	NOV 19	-4.94	2.02	291.9	-4.94	1.67	280.3	-4.94	1.37	270.7	-4.94	1.12	262.7	-4.94	.90	255.7
JAN 10	DEC 3	-4.78	1.82	253.2	-4.78	1.48	242.7	-4.78	1.18	234.1	-4.78	.93	226.9	-4.78	.72	220.7
	DEC 22	-4.68	1.69	231.1	-4.68	1.36	221.2	-4.68	1.07	213.1	-4.68	.82	206.5	-4.68	.61	200.8
		YEAR 216.077		R.I. .4111	YEAR 209.879		R.I. .3993	YEAR 204.228		R.I. .3886	YEAR 199.105		R.I. .3788	YEAR 194.432		R.I. .3699

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 38 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	35.6		6.5	33.0		12.5	30.2		17.9	27.4		22.7	24.6		27.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	6.78	1016.6	-7.32	6.26	1008.6	-7.32	5.78	997.2	-7.32	5.35	983.0	-7.32	4.96	966.6
JUN 1 JUL 12	-7.22	6.69	1001.7	-7.22	6.18	995.6	-7.22	5.71	986.2	-7.22	5.29	973.7	-7.22	4.91	959.0
MAY 18 JUL 27	-7.06	6.54	975.2	-7.06	6.05	972.4	-7.06	5.59	966.0	-7.06	5.18	956.6	-7.06	4.81	944.6
MAY 3 AUG 10	-6.84	6.34	935.4	-6.84	5.86	937.0	-6.84	5.43	935.0	-6.84	5.04	929.6	-6.84	4.69	921.4
APR 19 AUG 25	-6.58	6.10	882.2	-6.58	5.65	888.9	-6.58	5.24	891.9	-6.58	4.87	891.4	-6.58	4.54	887.7
APR 4 SEP 9	-6.29	5.84	817.5	-6.29	5.41	829.6	-6.29	5.03	837.9	-6.29	4.68	842.4	-6.29	4.37	843.4
MAR 21 SEP 23	-6.00	5.57	743.0	-6.00	5.17	760.1	-6.00	4.81	773.5	-6.00	4.48	782.9	-6.00	4.20	788.5
MAR 7 OCT 8	-5.71	5.30	664.0	-5.71	4.92	685.5	-5.71	4.59	703.3	-5.71	4.29	717.0	-5.71	4.03	726.9
FEB 20 OCT 22	-5.42	5.04	586.3	-5.42	4.69	611.2	-5.42	4.38	632.5	-5.42	4.10	649.8	-5.42	3.86	663.0
FEB 7 NOV 5	-5.16	4.80	515.1	-5.16	4.47	542.5	-5.16	4.18	566.4	-5.16	3.93	586.2	-5.16	3.71	602.0
JAN 23 NOV 19	-4.94	4.60	457.0	-4.94	4.29	485.9	-4.94	4.02	511.4	-4.94	3.79	532.9	-4.94	3.58	550.4
JAN 10 DEC 3	-4.78	4.45	415.8	-4.78	4.16	445.5	-4.78	3.90	471.9	-4.78	3.68	494.4	-4.78	3.49	512.9
DEC 22	-4.68	4.36	391.7	-4.68	4.07	421.8	-4.68	3.83	448.5	-4.68	3.62	471.5	-4.68	3.43	490.5
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	266.053		.5062	271.099		.5158	274.842		.5229	277.262		.5275	278.451		.5298

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	21.9		30.8	19.4		34.2	17.0		37.1	14.8		39.7	12.8		42.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.32	4.62	948.7	-7.32	4.31	930.0	-7.32	4.03	911.1	-7.32	3.79	892.5	-7.32	3.57	874.3
JUN 1 JUL 12	-7.22	4.57	942.6	-7.22	4.26	925.3	-7.22	4.00	907.5	-7.22	3.76	890.0	-7.22	3.55	872.7
MAY 18 JUL 27	-7.06	4.49	930.8	-7.06	4.19	915.7	-7.06	3.94	900.0	-7.06	3.71	884.1	-7.06	3.50	868.4
MAY 3 AUG 10	-6.84	4.37	911.0	-6.84	4.10	899.1	-6.84	3.85	886.1	-6.84	3.63	873.7	-6.84	3.44	859.1
APR 19 AUG 25	-6.58	4.24	881.4	-6.58	3.98	873.1	-6.58	3.75	863.5	-6.58	3.55	853.0	-6.58	3.36	842.1
APR 4 SEP 9	-6.29	4.10	847.1	-6.29	3.85	837.2	-6.29	3.64	831.1	-6.29	3.45	823.9	-6.29	3.28	815.8
MAR 21 SEP 23	-6.00	3.95	790.9	-6.00	3.72	790.8	-6.00	3.52	788.2	-6.00	3.35	784.1	-6.00	3.20	779.0
MAR 7 OCT 8	-5.71	3.79	733.2	-5.71	3.59	736.8	-5.71	3.41	737.4	-5.71	3.25	736.4	-5.71	3.11	734.0
FEB 20 OCT 22	-5.42	3.64	671.5	-5.42	3.46	679.2	-5.42	3.30	682.7	-5.42	3.16	684.4	-5.42	3.03	684.4
FEB 7 NOV 5	-5.16	3.50	614.1	-5.16	3.35	627.6	-5.16	3.20	638.9	-5.16	3.07	642.6	-5.16	2.95	643.8
JAN 23 NOV 19	-4.94	3.38	564.2	-4.94	3.25	584.7	-4.94	3.11	602.3	-4.94	3.00	617.1	-4.94	2.88	627.1
JAN 10 DEC 3	-4.78	3.28	527.6	-4.78	3.16	553.2	-4.78	3.05	576.4	-4.78	2.94	594.1	-4.78	2.84	606.3
DEC 22	-4.68	3.21	504.0	-4.68	3.10	537.8	-4.68	2.99	568.1	-4.68	2.89	593.1	-4.68	2.80	610.2

NOTE - FOR SURFACES WITH SOME SHADING, THE TIME AND LOSS OF LY AND SS ARE REDUCED.

SLOPE

		60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
		THETA 31.9		ALPHA 57.3	THETA 30.3		ALPHA 41.6	THETA 28.7		ALPHA 45.4	THETA 27.2		ALPHA 48.8	THETA 25.8		ALPHA 51.8
		SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22		-7.32	4.56	953.1	-7.32	4.21	935.6	-7.32	3.89	918.1	-7.32	3.61	901.1	-7.32	3.36	884.6
JUN 1	JUL 12	-7.22	4.48	939.4	-7.22	4.13	922.6	-7.22	3.82	905.8	-7.22	3.55	889.4	-7.22	3.30	873.5
MAY 18	JUL 27	-7.06	4.35	915.0	-7.06	4.01	899.4	-7.06	3.71	883.8	-7.06	3.44	868.4	-7.06	3.20	853.5
MAY 3	AUG 10	-6.84	4.18	878.3	-6.84	3.85	864.4	-6.84	3.56	850.3	-6.84	3.30	836.5	-6.84	3.07	823.0
APR 19	AUG 25	-6.58	3.97	826.9	-6.58	3.66	817.1	-6.58	3.38	805.0	-6.58	3.13	793.0	-6.58	2.91	781.2
APR 4	SEP 9	-6.29	3.75	768.9	-6.29	3.45	759.2	-6.29	3.18	749.3	-6.29	2.94	739.3	-6.29	2.73	729.4
MAR 21	SEP 23	-6.00	3.51	699.3	-6.00	3.23	692.0	-6.00	2.97	684.2	-6.00	2.75	676.3	-6.00	2.55	668.3
MAR 7	OCT 8	-5.71	3.28	625.3	-5.71	3.00	620.2	-5.71	2.76	614.5	-5.71	2.55	608.6	-5.71	2.37	602.5
FEB 20	OCT 22	-5.42	3.06	552.3	-5.42	2.79	549.1	-5.42	2.57	545.3	-5.42	2.37	541.1	-5.42	2.19	536.6
FEB 7	NOV 5	-5.16	2.85	485.4	-5.16	2.60	483.7	-5.16	2.38	481.3	-5.16	2.20	478.6	-5.16	2.03	475.5
JAN 23	NOV 19	-4.94	2.67	430.6	-4.94	2.44	430.0	-4.94	2.23	428.7	-4.94	2.05	427.0	-4.94	1.90	425.0
JAN 10	DEC 3	-4.78	2.55	391.7	-4.78	2.32	391.8	-4.78	2.12	391.3	-4.78	1.95	390.3	-4.78	1.80	388.8
DEC 22		-4.68	2.47	368.9	-4.68	2.24	369.3	-4.68	2.05	369.2	-4.68	1.89	368.6	-4.68	1.74	367.5
		YEAR 250.076		R.I. .4758	YEAR 247.138		R.I. .4702	YEAR 244.076		R.I. .4644	YEAR 240.976		R.I. .4585	YEAR 237.875		R.I. .4526

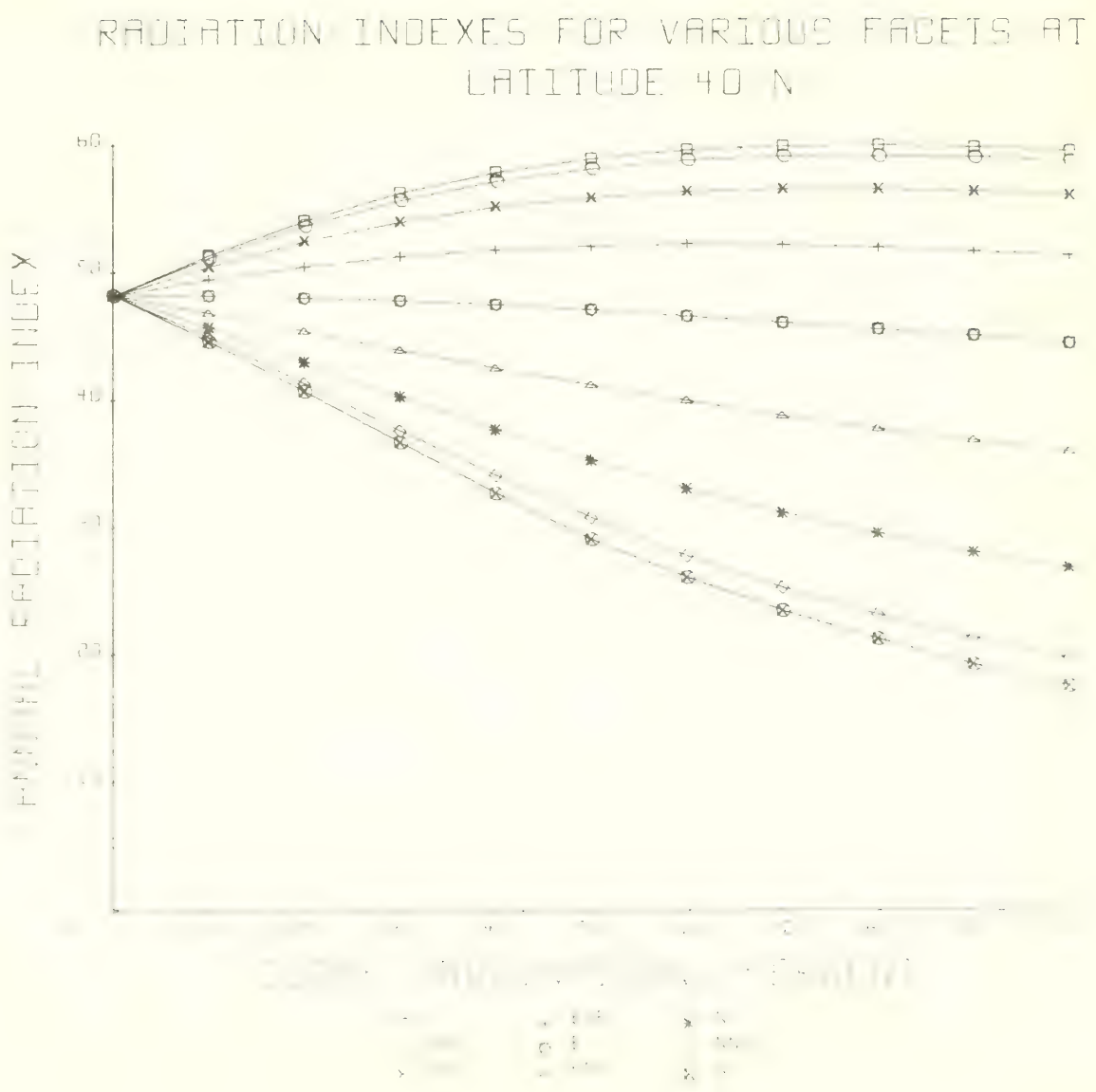
NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 40 N

		SR	SS	LY
JUN 22		-7.43	7.43	1022.7
JUN 1	JUL 12	-7.32	7.32	1004.2
MAY 18	JUL 27	-7.14	7.14	971.5
MAY 5	AUG 10	-6.90	6.90	923.5
APR 19	AUG 25	-6.62	6.62	860.7
APR 4	SEP 9	-6.32	6.32	786.3
MAR 21	SEP 23	-6.00	6.00	702.5
MAR 7	OCT 8	-5.68	5.68	615.6
FEB 20	OCT 24	-5.38	5.38	531.8
FEB 7	NOV 5	-5.10	5.10	456.5
JAN 23	NOV 19	-4.86	4.86	395.9
JAN 10	DEC 3	-4.68	4.68	353.5
DEC 22		-4.57	4.57	328.9

YEAR	R.I.
253.65*	.4826



ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	45.7		0.0	51.3		0.0	56.7		0.0	61.8		0.0	66.6		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	7.43	1021.6	-7.43	7.43	1010.7	-7.43	7.43	991.1	-7.43	7.43	964.5	-7.43	7.43	932.6
JUN 1 JUL 12	-7.32	7.32	998.1	-7.32	7.32	982.6	-7.32	7.32	958.8	-7.32	7.32	928.4	-7.32	7.32	893.4
MAY 18 JUL 27	-7.14	7.14	957.3	-7.14	7.14	934.2	-7.14	7.14	903.5	-7.14	7.14	867.1	-7.14	7.14	826.8
MAY 3 AUG 10	-6.90	6.90	898.3	-6.90	6.90	865.0	-6.90	6.90	825.2	-6.90	6.90	780.8	-6.90	6.90	733.7
APR 19 AUG 25	-6.62	6.62	823.1	-6.62	6.62	778.2	-6.62	6.62	728.1	-6.62	6.62	674.7	-6.62	6.62	619.9
APR 4 SEP 9	-6.32	6.32	735.9	-6.32	6.32	679.4	-6.32	6.32	619.0	-6.32	6.32	556.7	-6.32	6.32	494.4
MAR 21 SEP 23	-6.00	6.00	640.3	-6.00	6.00	573.2	-6.00	6.00	503.5	-6.00	6.00	433.4	-6.00	6.00	364.7
MAR 7 OCT 8	-5.61	5.61	543.6	-5.53	5.53	468.2	-5.42	5.42	391.7	-5.29	5.29	316.5	-5.12	5.12	244.6
FEB 20 OCT 22	-5.24	5.24	452.8	-5.07	5.07	372.1	-4.86	4.86	292.4	-4.59	4.59	216.3	-4.24	4.24	146.2
FEB 7 NOV 5	-4.89	4.89	373.2	-4.64	4.64	290.2	-4.33	4.33	210.5	-3.91	3.91	137.2	-3.33	3.33	73.4
JAN 23 NOV 19	-4.59	4.59	310.6	-4.27	4.27	227.5	-3.85	3.85	150.1	-3.28	3.28	82.0	-2.40	2.40	28.0
JAN 10 DEC 3	-4.37	4.37	267.7	-3.98	3.98	185.5	-3.47	3.47	111.1	-2.75	2.75	48.6	-1.43	1.43	6.0
DEC 22	-4.23	4.23	243.2	-3.81	3.81	162.1	-3.24	3.24	90.0	-2.39	2.39	32.1	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	234.548		.4462	214.006		.4072	192.933		.3671	172.271		.3278	153.243		.2916

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	71.0		0.0	75.0		0.0	78.7		0.0	82.0		0.0	85.0		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	7.43	897.5	-7.43	7.43	860.7	-7.43	7.43	823.6	-7.43	7.43	787.0	-7.43	7.43	751.4
JUN 1 JUL 12	-7.32	7.32	855.6	-7.32	7.32	816.5	-7.32	7.32	777.5	-7.32	7.32	739.4	-7.32	7.32	702.6
MAY 18 JUL 27	-7.14	7.14	784.6	-7.14	7.14	741.8	-7.14	7.14	699.7	-7.14	7.14	659.2	-7.14	7.14	620.4
MAY 3 AUG 10	-6.90	6.90	685.6	-6.90	6.90	638.1	-6.90	6.90	592.1	-6.90	6.90	548.4	-6.90	6.90	507.0
APR 19 AUG 25	-6.62	6.62	565.5	-6.62	6.62	512.7	-6.62	6.62	462.6	-6.62	6.62	415.5	-6.62	6.62	371.5
APR 4 SEP 9	-6.32	6.32	434.0	-6.32	6.32	376.3	-6.32	6.32	322.2	-6.32	6.32	272.2	-6.32	6.32	225.8
MAR 21 SEP 23	-6.00	6.00	299.1	-6.00	6.00	237.4	-6.00	6.00	180.2	-6.00	6.00	127.9	-6.00	6.00	79.9
MAR 7 OCT 8	-4.89	4.89	177.6	-4.56	4.56	116.8	-4.03	4.03	63.4	-3.04	3.04	20.2	0.00	0.00	0.0
FEB 20 OCT 22	-3.73	3.73	84.3	-2.93	2.93	33.6	-1.05	1.05	1.2	0.00	0.00	0.0	0.00	0.00	0.0
FEB 7 NOV 5	-2.40	2.40	23.5	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	137.380		.2614	123.821		.2356	112.019		.2131	101.887		.1938	92.944		.1768

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 40 N
ASPECT S -

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	34.3	0.0	28.7	0.0	23.3	0.0	18.2	0.0	13.4	0.0

		SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22		-7.15	7.15	1015.3	-6.92	6.92	1001.1	-6.72	6.72	980.5	-6.55	6.55	954.7	-6.40	6.40	925.0
JUN 1	JUL 12	-7.06	7.06	1001.7	-6.85	6.85	992.0	-6.67	6.67	975.6	-6.51	6.51	953.5	-6.37	6.37	927.2
MAY 18	JUL 27	-6.92	6.92	977.2	-6.74	6.74	975.1	-6.58	6.58	965.8	-6.44	6.44	950.2	-6.32	6.32	929.7
MAY 3	AUG 10	-6.73	6.73	940.2	-6.59	6.59	948.6	-6.46	6.46	949.1	-6.35	6.35	942.6	-6.25	6.25	930.3
APR 19	AUG 25	-6.50	6.50	890.2	-6.40	6.40	911.0	-6.32	6.32	923.3	-6.24	6.24	927.8	-6.18	6.18	925.7
APR 4	SEP 9	-6.26	6.26	829.0	-6.21	6.21	863.0	-6.16	6.16	888.0	-6.12	6.12	904.6	-6.09	6.09	913.7
MAR 21	SEP 23	-6.00	6.00	757.8	-6.00	6.00	804.6	-6.00	6.00	842.3	-6.00	6.00	871.2	-6.00	6.00	892.0
MAR 7	OCT 8	-5.68	5.68	681.6	-5.68	5.68	739.6	-5.68	5.68	788.7	-5.68	5.68	828.9	-5.68	5.68	860.5
FEB 20	OCT 22	-5.38	5.38	605.9	-5.38	5.38	672.7	-5.38	5.38	730.8	-5.38	5.38	779.9	-5.38	5.38	820.3
FEB 7	NOV 5	-5.10	5.10	536.1	-5.10	5.10	608.9	-5.10	5.10	673.4	-5.10	5.10	729.0	-5.10	5.10	775.8
JAN 23	NOV 19	-4.86	4.86	478.6	-4.86	4.86	555.0	-4.86	4.86	623.5	-4.86	4.86	683.3	-4.86	4.86	734.3
JAN 10	DEC 3	-4.68	4.68	437.7	-4.68	4.68	515.9	-4.68	4.68	586.5	-4.68	4.68	648.6	-4.68	4.68	702.0
DEC 22		-4.57	4.57	413.6	-4.57	4.57	492.6	-4.57	4.57	564.1	-4.57	4.57	627.2	-4.57	4.57	681.7

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
270.580	.5148	284.802	.5419	296.107	.5634	304.560	.5795	310.403	.5906

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	9.0	0.0	5.0	0.0	1.3	0.0	-2.0	0.0	-5.0	0.0

		SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22		-6.26	6.26	893.0	-6.15	6.15	859.8	-6.04	6.04	826.6	-5.94	5.94	794.2	-5.85	5.85	762.9
JUN 1	JUL 12	-6.25	6.25	898.2	-6.13	6.13	867.6	-6.04	6.04	836.7	-5.95	5.95	806.2	-5.87	5.87	776.5
MAY 18	JUL 27	-6.21	6.21	905.8	-6.12	6.12	879.7	-6.03	6.03	852.7	-5.95	5.95	825.6	-5.88	5.88	798.8
MAY 3	AUG 10	-6.17	6.17	913.7	-6.09	6.09	894.1	-6.02	6.02	872.7	-5.96	5.96	850.5	-5.91	5.91	828.1
APR 19	AUG 25	-6.12	6.12	918.2	-6.06	6.06	906.8	-6.02	6.02	892.6	-5.97	5.97	876.8	-5.94	5.94	859.9
APR 4	SEP 9	-6.06	6.06	916.5	-6.03	6.03	914.4	-6.01	6.01	908.6	-5.99	5.99	900.2	-5.97	5.97	890.0
MAR 21	SEP 23	-6.00	6.00	905.7	-6.00	6.00	913.6	-6.00	6.00	916.9	-6.00	6.00	916.6	-6.00	6.00	913.6
MAR 7	OCT 8	-5.68	5.68	884.4	-5.68	5.68	901.7	-5.68	5.68	913.5	-5.68	5.68	921.1	-5.68	5.68	925.2
FEB 20	OCT 22	-5.38	5.38	852.5	-5.38	5.38	877.6	-5.38	5.38	896.7	-5.38	5.38	910.7	-5.38	5.38	920.7
FEB 7	NOV 5	-5.10	5.10	814.3	-5.10	5.10	845.3	-5.10	5.10	869.9	-5.10	5.10	889.0	-5.10	5.10	903.5
JAN 23	NOV 19	-4.86	4.86	776.9	-4.86	4.86	812.0	-4.86	4.86	840.3	-4.86	4.86	863.0	-4.86	4.86	881.1
JAN 10	DEC 3	-4.68	4.68	747.0	-4.68	4.68	784.4	-4.68	4.68	815.0	-4.68	4.68	839.6	-4.68	4.68	859.7
DEC 22		-4.57	4.57	727.5	-4.57	4.57	766.5	-4.57	4.57	798.2	-4.57	4.57	824.1	-4.57	4.57	845.3

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
313.986	.5976	315.722	.6007	316.005	.6012	315.197	.5997	313.588	.5966

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 40 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 45.2		ALPHA 3.1	THETA 50.3		ALPHA 6.7	THETA 55.0		ALPHA 11.1	THETA 59.3		ALPHA 16.2	THETA 63.1		ALPHA 22.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	7.43	1021.3	-7.43	7.43	1010.1	-7.43	7.43	990.2	-7.43	7.43	963.3	-7.43	7.43	931.3
JUN 1 JUL 12	-7.32	7.32	998.2	-7.32	7.32	982.7	-7.32	7.32	959.0	-7.32	7.32	928.7	-7.32	7.32	893.8
MAY 18 JUL 27	-7.14	7.14	958.0	-7.14	7.14	935.6	-7.14	7.14	905.5	-7.14	7.14	869.7	-7.14	7.14	830.0
MAY 3 AUG 10	-6.90	6.86	899.3	-6.90	6.86	868.1	-6.90	6.83	829.8	-6.90	6.79	786.7	-6.90	6.74	740.8
APR 19 AUG 25	-6.62	6.54	825.7	-6.62	6.45	782.5	-6.62	6.33	736.1	-6.62	6.19	685.5	-6.62	6.01	633.6
APR 4 SEP 9	-6.32	5.17	739.6	-6.32	6.00	667.3	-6.32	5.80	631.5	-6.32	5.56	574.3	-6.32	5.27	517.8
MAR 21 SEP 23	-6.00	5.79	645.3	-6.00	5.55	584.0	-6.00	5.26	521.3	-6.00	4.92	459.3	-6.00	4.52	400.2
MAR 7 OCT 8	-5.68	5.41	549.6	-5.68	5.10	481.5	-5.68	4.72	414.0	-5.68	4.29	349.5	-5.68	3.77	290.2
FEB 20 OCT 22	-5.38	5.09	459.4	-5.38	4.66	386.9	-5.38	4.20	317.1	-5.38	3.66	252.5	-5.38	3.03	195.2
FEB 7 NOV 5	-5.10	4.70	380.2	-5.10	4.24	305.6	-5.10	3.70	235.6	-5.10	3.06	173.0	-5.10	2.30	119.7
JAN 23 NOV 19	-4.83	4.41	317.7	-4.78	3.88	242.8	-4.73	3.26	174.2	-4.66	2.51	114.8	-4.57	1.61	66.6
JAN 10 DEC 3	-4.61	4.19	274.8	-4.51	3.61	200.5	-4.39	2.92	134.0	-4.23	2.07	78.2	-3.98	1.02	36.5
DEC 22	-4.47	4.06	250.2	-4.35	3.45	176.7	-4.18	2.71	112.0	-3.94	1.79	59.0	-3.56	.60	20.6
	YEAR 236.051		R.I. .4491	YEAR 217.243		R.I. .4133	YEAR 196.087		R.I. .3769	YEAR 179.399		R.I. .3413	YEAR 161.959		R.I. .3081

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 66.3		ALPHA 29.3	THETA 68.8		ALPHA 37.4	THETA 70.7		ALPHA 46.5	THETA 72.0		ALPHA 56.1	THETA 72.7		ALPHA 65.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	7.43	896.0	-7.43	7.43	859.0	-7.43	7.43	821.6	-7.43	7.43	785.0	-7.43	7.43	749.3
JUN 1 JUL 12	-7.32	7.32	856.0	-7.32	7.32	817.0	-7.32	7.32	777.9	-7.32	7.32	739.9	-7.32	7.32	703.2
MAY 18 JUL 27	-7.14	7.14	788.3	-7.14	7.14	745.9	-7.14	7.14	704.2	-7.14	7.14	664.0	-7.14	7.14	625.5
MAY 3 AUG 10	-6.90	6.67	694.0	-6.90	6.58	647.5	-6.90	6.43	602.5	-6.90	6.22	559.9	-6.90	5.87	519.8
APR 19 AUG 25	-6.62	5.78	582.4	-6.62	5.50	533.0	-6.62	5.14	486.8	-6.62	4.69	444.6	-6.62	4.17	406.5
APR 4 SEP 9	-6.32	4.91	463.8	-6.32	4.49	413.7	-6.32	4.00	368.5	-6.32	3.44	328.9	-6.32	2.85	294.8
MAR 21 SEP 23	-6.00	4.05	345.7	-6.00	3.51	297.2	-6.00	2.90	255.3	-6.00	2.26	220.4	-6.00	1.61	191.9
MAR 7 OCT 8	-5.68	3.18	237.7	-5.68	2.52	193.0	-5.68	1.81	156.5	-5.68	1.08	128.0	-5.68	.38	106.2
FEB 20 OCT 22	-5.38	2.32	146.9	-5.38	1.51	108.1	-5.38	.67	78.7	-5.38	-.17	57.8	-5.38	-.94	43.5
FEB 7 NOV 5	-5.10	1.43	77.2	-5.10	.44	45.8	-5.10	-.63	25.0	-5.10	-1.69	12.8	-5.10	-2.64	6.6
JAN 23 NOV 19	-4.43	.52	31.1	-4.17	-.82	8.8	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	-3.52	-.38	8.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-2.54	-1.37	.4	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 146.450		R.I. .2786	YEAR 133.376		R.I. .2538	YEAR 122.177		R.I. .2325	YEAR 112.556		R.I. .2141	YEAR 104.131		R.I. .1981

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 40 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	34.7		2.7	29.4		4.9	24.3		6.9	19.5		8.7	15.0		10.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.34	6.99	1016.1	-7.28	6.62	1003.4	-7.22	6.29	985.1	-7.17	6.01	961.9	-7.13	5.76	935.2
JUN 1 JUL 12	-7.26	6.90	1002.1	-7.21	6.55	993.7	-7.16	6.24	979.3	-7.13	5.97	959.8	-7.09	5.73	936.3
MAY 18 JUL 27	-7.11	6.76	977.0	-7.09	6.43	975.8	-7.07	6.15	968.2	-7.05	5.90	954.8	-7.04	5.68	937.9
MAY 3 AUG 10	-6.90	6.56	939.2	-6.90	6.27	947.9	-6.90	6.02	949.6	-6.90	5.80	944.9	-6.90	5.60	934.8
APR 19 AUG 25	-6.62	6.33	888.3	-6.62	6.09	908.5	-6.62	5.87	921.1	-6.62	5.68	926.7	-6.62	5.52	926.1
APR 4 SEP 9	-6.32	6.08	826.1	-6.32	5.88	858.2	-6.32	5.71	882.3	-6.32	5.56	898.7	-6.32	5.42	908.2
MAR 21 SEP 23	-6.00	5.82	753.7	-6.00	5.67	797.2	-6.00	5.54	832.5	-6.00	5.42	859.5	-6.00	5.32	878.9
MAR 7 OCT 8	-5.68	5.56	676.5	-5.68	5.46	729.9	-5.68	5.37	775.0	-5.68	5.29	811.6	-5.68	5.22	840.2
FEB 20 OCT 22	-5.38	5.31	600.1	-5.38	5.25	661.4	-5.38	5.20	714.4	-5.38	5.16	756.8	-5.38	5.12	795.0
FEB 7 NOV 5	-5.10	5.08	529.8	-5.10	5.07	596.6	-5.10	5.05	655.4	-5.10	5.04	705.8	-5.10	5.03	747.9
JAN 23 NOV 19	-4.86	4.86	472.2	-4.86	4.86	542.3	-4.86	4.86	604.9	-4.86	4.86	659.3	-4.86	4.86	705.1
JAN 10 DEC 3	-4.68	4.68	431.1	-4.68	4.68	503.0	-4.68	4.68	567.6	-4.68	4.68	624.2	-4.68	4.68	672.6
DEC 22	-4.57	4.57	407.0	-4.57	4.57	479.6	-4.57	4.57	545.1	-4.57	4.57	602.7	-4.57	4.57	652.3
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	269.325		.5124	282.536		.5375	293.058		.5576	300.929		.5725	306.363		.5829

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	10.8		11.6	6.9		12.8	3.4		13.9	.3		14.8	-2.6		15.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.09	5.55	906.2	-7.05	5.35	876.1	-7.02	5.18	845.9	-7.00	5.02	816.3	-6.97	4.88	787.6
JUN 1 JUL 12	-7.06	5.52	910.3	-7.04	5.34	882.7	-7.02	5.17	854.7	-7.00	5.02	827.0	-6.98	4.88	800.0
MAY 18 JUL 27	-7.03	5.48	915.8	-7.01	5.31	892.6	-7.00	5.16	868.5	-6.99	5.02	844.1	-6.99	4.89	820.6
MAY 3 AUG 10	-6.90	5.45	920.8	-6.90	5.28	903.9	-6.90	5.14	885.2	-6.90	5.02	865.6	-6.90	4.90	845.7
APR 19 AUG 25	-6.62	5.37	920.5	-6.62	5.24	911.2	-6.62	5.12	899.3	-6.62	5.01	885.7	-6.62	4.92	871.6
APR 4 SEP 9	-6.32	5.30	911.8	-6.32	5.19	910.6	-6.32	5.10	906.3	-6.32	5.01	899.2	-6.32	4.93	890.4
MAR 21 SEP 23	-6.00	5.23	891.8	-6.00	5.15	899.1	-6.00	5.08	902.1	-6.00	5.01	901.8	-6.00	4.95	899.5
MAR 7 OCT 8	-5.68	5.16	861.5	-5.68	5.10	876.7	-5.68	5.05	886.8	-5.68	5.01	892.9	-5.68	4.97	895.9
FEB 20 OCT 22	-5.38	5.09	823.6	-5.38	5.06	845.5	-5.38	5.03	861.9	-5.38	5.01	873.7	-5.38	4.99	881.8
FEB 7 NOV 5	-5.10	5.03	782.1	-5.10	5.02	809.5	-5.10	5.01	830.9	-5.10	5.01	847.3	-5.10	5.00	859.6
JAN 23 NOV 19	-4.86	4.86	743.6	-4.86	4.86	774.8	-4.86	4.86	799.9	-4.86	4.86	819.1	-4.86	4.86	833.4
JAN 10 DEC 3	-4.68	4.68	713.2	-4.68	4.68	746.7	-4.68	4.68	773.9	-4.68	4.68	795.3	-4.68	4.68	810.1
DEC 22	-4.57	4.57	694.0	-4.57	4.57	726.6	-4.57	4.57	757.0	-4.57	4.57	780.0	-4.57	4.57	795.4
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	309.56		.5892	311.205		.5922	311.485		.5926	310.681		.5911	309.12		.5881

NOTE - FOR ANGLES IN MID-RANGE COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 40 N
ASPECT NE - NW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	43.9		5.6	47.4		11.8	50.5		18.6	52.9		25.8	54.8		33.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	7.28	1020.7	-7.43	7.10	1009.3	-7.43	6.88	989.9	-7.43	6.62	964.3	-7.43	6.32	934.5
JUN 1 JUL 12	-7.32	7.15	998.7	-7.32	6.95	984.3	-7.32	6.71	962.5	-7.32	6.43	935.0	-7.32	6.11	903.8
MAY 18 JUL 27	-7.14	6.94	960.4	-7.14	6.71	941.2	-7.14	6.44	915.4	-7.14	6.12	884.9	-7.14	5.77	851.7
MAY 3 AUG 10	-6.90	6.66	904.9	-6.90	6.39	879.4	-6.90	6.08	848.5	-6.90	5.72	814.2	-6.90	5.33	778.6
APR 19 AUG 25	-6.62	6.34	833.7	-6.62	6.02	801.1	-6.62	5.66	764.8	-6.62	5.26	726.7	-6.62	4.84	688.9
APR 4 SEP 9	-6.32	5.99	750.7	-6.32	5.62	711.2	-6.32	5.22	669.9	-6.32	4.78	628.7	-6.32	4.32	589.3
MAR 21 SEP 23	-6.00	5.63	659.1	-6.00	5.21	613.7	-6.00	4.76	568.4	-6.00	4.28	525.1	-6.00	3.78	485.3
MAR 7 OCT 8	-5.68	5.26	565.8	-5.68	4.80	515.8	-5.68	4.30	468.0	-5.68	3.78	423.9	-5.68	3.25	384.8
FEB 20 OCT 22	-5.38	4.91	477.3	-5.38	4.40	424.5	-5.38	3.86	375.7	-5.38	3.29	332.1	-5.38	2.72	294.7
FEB 7 NOV 5	-5.10	4.59	399.2	-5.10	4.03	345.2	-5.10	3.44	296.6	-5.10	2.83	254.6	-5.10	2.23	219.8
JAN 23 NOV 19	-4.86	4.31	337.2	-4.86	3.71	283.1	-4.86	3.08	235.7	-4.86	2.43	195.8	-4.86	1.79	163.7
JAN 10 DEC 3	-4.68	4.10	294.4	-4.68	3.47	240.8	-4.68	2.81	194.7	-4.68	2.13	156.6	-4.68	1.46	127.0
DEC 22	-4.57	3.98	269.8	-4.57	3.33	216.8	-4.57	2.64	171.6	-4.57	1.93	135.0	-4.57	1.24	106.8
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	240.266		.4571	226.163		.4303	212.023		.4034	198.416		.3775	185.789		.3535

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	56.1		40.7	56.8		47.9	57.2		54.6	57.2		60.7	56.9		66.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	5.97	902.6	-7.43	5.59	870.1	-7.43	5.19	838.5	-7.43	4.78	808.8	-7.43	4.37	781.2
JUN 1 JUL 12	-7.32	5.74	871.0	-7.32	5.35	838.2	-7.32	4.94	806.6	-7.32	4.53	777.1	-7.32	4.13	749.9
MAY 18 JUL 27	-7.14	5.38	817.7	-7.14	4.97	784.4	-7.14	4.56	752.9	-7.14	4.15	723.9	-7.14	3.75	697.5
MAY 3 AUG 10	-6.90	4.92	743.3	-6.90	4.49	709.7	-6.90	4.07	678.6	-6.90	3.66	650.6	-6.90	3.27	625.3
APR 19 AUG 25	-6.62	4.40	652.8	-6.62	3.95	619.3	-6.62	3.52	589.2	-6.62	3.11	562.5	-6.62	2.73	538.9
APR 4 SEP 9	-6.32	3.85	553.1	-6.32	3.39	520.5	-6.32	2.95	491.9	-6.32	2.54	467.2	-6.32	2.16	445.8
MAR 21 SEP 23	-6.00	3.29	449.8	-6.00	2.81	418.9	-6.00	2.36	392.6	-6.00	1.95	370.4	-6.00	1.59	351.5
MAR 7 OCT 8	-5.68	2.72	351.1	-5.68	2.23	322.7	-5.68	1.77	299.2	-5.68	1.37	279.9	-5.68	1.01	263.9
FEB 20 OCT 22	-5.38	2.18	263.7	-5.38	1.66	238.3	-5.38	1.20	218.0	-5.38	.79	201.7	-5.38	.44	188.6
FEB 7 NOV 5	-5.10	1.65	191.8	-5.10	1.12	169.7	-5.10	.65	152.6	-5.10	.25	139.4	-5.10	-.10	128.9
JAN 23 NOV 19	-4.86	1.19	138.7	-4.86	.64	119.8	-4.86	.16	105.5	-4.86	-.24	94.9	-4.86	-.58	86.7
JAN 10 DEC 3	-4.68	.83	104.5	-4.68	.27	88.0	-4.68	-.22	75.9	-4.68	-.62	67.2	-4.68	-.96	60.7
DEC 22	-4.57	.60	86.0	-4.57	.03	70.9	-4.57	-.46	60.2	-4.57	-.87	52.7	-4.57	-1.20	47.1
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	174.409		.3318	164.352		.3127	155.605		.2961	148.062		.2817	141.525		.2693

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 40 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	35.8		5.0	31.6		9.4	27.4		13.2	23.3		16.6	19.4		19.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	6.89	1017.9	-7.43	6.41	1008.8	-7.43	5.99	995.5	-7.43	5.61	978.5	-7.43	5.28	958.6
JUN 1 JUL 12	-7.32	6.80	1002.8	-7.32	6.33	997.1	-7.32	5.92	987.0	-7.32	5.56	972.9	-7.32	5.24	955.7
MAY 18 JUL 27	-7.14	6.65	976.0	-7.14	6.21	976.0	-7.14	5.82	971.1	-7.14	5.47	961.9	-7.14	5.17	949.0
MAY 3 AUG 10	-6.90	6.44	935.9	-6.90	6.03	943.4	-6.90	5.67	945.7	-6.90	5.35	943.1	-6.90	5.07	936.3
APR 19 AUG 25	-6.62	6.20	902.2	-6.62	5.83	898.5	-6.62	5.50	909.1	-6.62	5.21	914.3	-6.62	4.95	914.6
APR 4 SEP 9	-6.32	5.94	817.1	-6.32	5.61	842.4	-6.32	5.31	861.7	-6.32	5.05	875.1	-6.32	4.83	882.9
MAR 21 SEP 23	-6.00	5.67	742.0	-6.00	5.37	775.9	-6.00	5.12	803.5	-6.00	4.89	824.7	-6.00	4.69	839.8
MAR 7 OCT 8	-5.68	5.40	662.4	-5.68	5.14	703.7	-5.68	4.92	738.5	-5.68	4.73	766.7	-5.68	4.56	786.4
FEB 20 OCT 22	-5.38	5.13	584.2	-5.38	4.92	631.2	-5.38	4.74	671.7	-5.38	4.57	705.4	-5.38	4.43	732.5
FEB 7 NOV 5	-5.10	4.89	512.6	-5.10	4.72	563.5	-5.10	4.56	608.1	-5.10	4.43	645.9	-5.10	4.32	677.0
JAN 23 NOV 19	-4.86	4.69	454.2	-4.86	4.54	507.4	-4.86	4.42	554.5	-4.86	4.31	595.0	-4.86	4.22	628.8
JAN 10 DEC 3	-4.68	4.54	412.8	-4.68	4.42	467.2	-4.68	4.31	515.7	-4.68	4.23	557.6	-4.68	4.15	593.6
DEC 22	-4.57	4.45	388.5	-4.57	4.34	443.4	-4.57	4.25	492.5	-4.57	4.17	535.1	-4.57	4.11	571.3
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	265.706		.5055	275.930		.5250	284.082		.5405	290.142		.5520	294.251		.5598

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	15.8		22.2	12.5		24.5	9.4		26.6	6.6		28.4	4.1		30.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	4.99	936.8	-7.43	4.73	913.8	-7.43	4.50	890.5	-7.43	4.30	867.6	-7.43	4.11	845.2
JUN 1 JUL 12	-7.32	4.96	936.2	-7.32	4.70	915.3	-7.32	4.48	893.8	-7.32	4.28	872.4	-7.32	4.10	851.3
MAY 18 JUL 27	-7.14	4.90	933.5	-7.14	4.66	916.0	-7.14	4.45	897.6	-7.14	4.26	878.9	-7.14	4.09	860.1
MAY 3 AUG 10	-6.90	4.82	926.1	-6.90	4.60	913.5	-6.90	4.40	899.3	-6.90	4.23	884.2	-6.90	4.07	868.7
APR 19 AUG 25	-6.62	4.73	910.9	-6.62	4.53	904.0	-6.62	4.35	894.8	-6.62	4.19	884.2	-6.62	4.05	872.6
APR 4 SEP 9	-6.32	4.63	885.9	-6.32	4.45	885.2	-6.32	4.29	881.5	-6.32	4.15	875.8	-6.32	4.02	868.5
MAR 21 SEP 23	-6.00	4.52	849.6	-6.00	4.36	855.0	-6.00	4.23	856.9	-6.00	4.10	856.0	-6.00	3.99	853.1
MAR 7 OCT 8	-5.68	4.41	804.3	-5.68	4.28	815.3	-5.68	4.16	822.3	-5.68	4.06	826.0	-5.68	3.97	827.3
FEB 20 OCT 22	-5.38	4.31	753.5	-5.38	4.20	769.3	-5.38	4.10	780.6	-5.38	4.02	788.4	-5.38	3.94	793.3
FEB 7 NOV 5	-5.10	4.22	701.9	-5.10	4.13	721.4	-5.10	4.05	736.2	-5.10	3.98	747.1	-5.10	3.92	755.0
JAN 23 NOV 19	-4.86	4.14	656.4	-4.86	4.07	678.4	-4.86	4.00	695.7	-4.86	3.95	708.9	-4.86	3.90	719.6
JAN 10 DEC 3	-4.68	4.08	622.2	-4.68	4.02	645.8	-4.68	3.97	664.6	-4.68	3.93	679.3	-4.68	3.88	690.8
DEC 22	-4.57	4.05	601.3	-4.57	4.00	625.7	-4.57	3.95	645.3	-4.57	3.91	660.9	-4.57	3.88	673.1
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	298.852		.5644	297.648		.5663	297.537		.5661	296.596		.5643	295.048		.5614

NOTE - FOR ALPHITS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	42.0	7.1		43.5	14.5		44.4	21.8		44.9	29.0		44.9	36.7	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	7.06	1020.4	-7.43	6.66	1011.1	-7.43	6.23	996.2	-7.43	5.78	977.4	-7.43	5.35	956.2
JUN 1 JUL 12	-7.32	6.94	1000.1	-7.32	6.53	989.5	-7.32	6.10	973.7	-7.32	5.69	954.4	-7.32	5.20	933.1
MAY 18 JUL 27	-7.14	6.75	964.6	-7.14	6.33	951.9	-7.14	5.89	934.7	-7.14	5.43	914.6	-7.14	4.99	893.1
MAY 3 AUG 10	-6.90	6.49	912.6	-6.90	6.06	897.2	-6.90	5.60	878.3	-6.90	5.14	857.3	-6.90	4.70	835.6
APR 19 AUG 25	-6.62	6.19	845.7	-6.62	5.74	827.1	-6.62	5.27	806.3	-6.62	4.81	784.6	-6.62	4.36	762.9
APR 4 SEP 9	-6.32	5.87	780.9	-6.32	5.39	745.4	-6.32	4.92	723.3	-6.32	4.44	700.7	-6.32	4.00	679.3
MAR 21 SEP 23	-6.00	5.53	719.1	-6.00	5.04	655.2	-6.00	4.55	631.5	-6.00	4.07	609.1	-6.00	3.62	588.5
MAR 7 OCT 8	-5.68	5.19	685.0	-5.68	4.68	563.2	-5.68	4.18	538.9	-5.68	3.69	516.9	-5.68	3.24	497.2
FEB 20 OCT 22	-5.38	4.86	651.9	-5.38	4.33	475.9	-5.38	3.82	451.7	-5.38	3.33	430.5	-5.38	2.88	412.2
FEB 7 NOV 5	-5.10	4.56	625.7	-5.10	4.01	398.9	-5.10	3.49	375.1	-5.10	2.99	354.9	-5.10	2.54	338.1
JAN 23 NOV 19	-4.86	4.30	604.9	-4.86	3.74	337.7	-4.86	3.20	314.7	-4.86	2.71	295.6	-4.86	2.26	280.2
JAN 10 DEC 3	-4.68	4.11	322.6	-4.68	3.54	295.5	-4.68	2.99	273.2	-4.68	2.49	255.1	-4.68	2.04	240.6
DEC 22	-4.57	3.99	297.5	-4.57	3.41	271.2	-4.57	2.86	249.4	-4.57	2.36	231.9	-4.57	1.91	218.2
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	146.405	.4685		138.771	.4543		131.110	.4397		123.666	.4256		116.690	.4123	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	44.6	41.9		44.0	47.5		43.2	52.4		42.4	56.8		41.4	60.6	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	4.90	934.2	-7.43	4.49	912.2	-7.43	4.12	890.9	-7.43	3.77	870.6	-7.43	3.46	851.9
JUN 1 JUL 12	-7.32	4.77	911.1	-7.32	4.36	889.3	-7.32	3.99	868.4	-7.32	3.65	848.6	-7.32	3.35	830.1
MAY 18 JUL 27	-7.14	4.56	871.2	-7.14	4.16	849.9	-7.14	3.79	829.5	-7.14	3.46	810.5	-7.14	3.16	792.7
MAY 3 AUG 10	-6.90	4.27	814.1	-6.90	3.88	793.5	-6.90	3.52	774.0	-6.90	3.20	756.0	-6.90	2.91	739.3
APR 19 AUG 25	-6.62	3.94	742.0	-6.62	3.55	722.3	-6.62	3.20	704.1	-6.62	2.89	687.4	-6.62	2.61	672.0
APR 4 SEP 9	-6.32	3.58	659.3	-6.32	3.20	640.9	-6.32	2.86	624.4	-6.32	2.56	609.0	-6.32	2.29	595.2
MAR 21 SEP 23	-6.00	3.21	569.1	-6.00	2.84	551.9	-6.00	2.51	537.5	-6.00	2.22	524.4	-6.00	1.96	512.4
MAR 7 OCT 8	-5.68	2.84	480.0	-5.68	2.47	464.9	-5.68	2.15	451.7	-5.68	1.87	440.1	-5.68	1.63	429.8
FEB 20 OCT 22	-5.38	2.48	396.6	-5.38	2.12	383.2	-5.38	1.81	371.8	-5.38	1.54	362.0	-5.38	1.30	353.3
FEB 7 NOV 5	-5.10	2.14	324.1	-5.10	1.79	312.4	-5.10	1.49	302.7	-5.10	1.23	294.4	-5.10	1.01	287.2
JAN 23 NOV 19	-4.86	1.86	267.7	-4.86	1.52	257.4	-4.86	1.22	248.9	-4.86	.97	241.9	-4.86	.76	235.9
JAN 10 DEC 3	-4.68	1.61	229.1	-4.68	1.31	219.9	-4.68	1.02	212.5	-4.68	.78	206.3	-4.68	.57	201.1
DEC 22	-4.57	1.42	207.9	-4.57	1.18	198.7	-4.57	.90	191.6	-4.57	.66	186.1	-4.57	.45	181.4
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	110.224	.4000		204.313	.3887		198.952	.3785		194.114	.3693		189.714	.3609	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LAT. [illegible] N
ASPECT E.E - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	37.5	6.7		[illegible]4.9	[illegible]2.8		32.1	18.3		29.2	23.1		26.3	27.5	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	6.86	1019.4	-7.43	6.33	1012.5	-7.43	5.84	1002.4	-7.43	5.39	989.4	-7.43	5.00	974.2
JUN [illegible] JUL 12	-7.32	6.76	1002.6	-7.32	6.24	997.9	-7.32	5.76	989.7	-7.32	5.33	976.6	-7.32	4.94	965.1
MAY 18 JUL 27	-7.14	6.60	973.4	-7.14	6.09	971.9	-7.14	5.63	967.0	-7.14	5.21	958.9	-7.14	4.84	948.3
MAY [illegible] AUG 10	-6.90	6.38	929.8	-6.90	5.90	932.8	-6.90	5.45	932.2	-6.90	5.05	928.4	-6.90	4.70	921.7
APR 14 AUG 25	-6.62	6.13	872.1	-6.62	5.66	880.3	-6.62	5.25	884.9	-6.62	4.87	885.7	-6.62	4.53	885.3
APR 4 SEP 9	-6.32	5.85	802.9	-6.32	5.41	816.4	-6.32	5.02	826.2	-6.32	4.67	832.4	-6.32	4.36	835.0
MAR 21 SEP 23	-6.00	5.56	724.0	-6.00	5.15	742.5	-6.00	4.78	757.3	-6.00	4.46	768.3	-6.00	4.17	775.5
MAR 7 OCT 6	-5.68	5.26	641.1	-5.68	4.88	663.9	-5.68	4.55	683.1	-5.68	4.25	698.3	-5.68	3.98	709.6
FEB 20 OCT 27	-5.38	4.99	560.4	-5.38	4.63	586.5	-5.38	4.32	609.0	-5.38	4.04	627.6	-5.38	3.80	642.2
FEB 7 NOV 9	-5.10	4.73	487.2	-5.10	4.40	515.4	-5.10	4.11	540.3	-5.10	3.86	561.3	-5.10	3.64	578.3
JAN 23 NOV 19	-4.86	4.51	427.8	-4.86	4.20	457.3	-4.86	3.93	483.6	-4.86	3.70	506.0	-4.86	3.50	524.6
JAN 10 DEC 3	-4.68	4.35	385.9	-4.68	4.06	416.1	-4.68	3.81	443.1	-4.68	3.59	466.3	-4.68	3.46	485.7
DEC 21	-4.57	4.25	361.5	-4.57	3.97	391.9	-4.57	3.73	419.2	-4.57	3.52	442.8	-4.57	3.34	462.6
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	260.189	.4950		265.595	.5053		269.781	.5133		272.869	.5188		274.328	.5219	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	33.6	31.4		21.0	34.6		18.6	37.5		16.4	40.1		14.3	42.4	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	4.65	957.4	-7.43	4.33	939.7	-7.43	4.06	921.7	-7.43	3.82	903.8	-7.43	3.60	886.3
JUN [illegible] JUL 12	-7.32	4.59	[illegible]	-7.32	4.29	933.6	-7.32	4.02	916.8	-7.32	3.78	900.1	-7.32	3.57	883.5
MAY 18 JUL 27	-7.14	4.50	935.7	-7.14	4.21	921.8	-7.14	3.95	907.7	-7.14	3.72	892.1	-7.14	3.54	877.4
MAY [illegible] AUG 10	-6.90	4.35	912.6	-6.90	4.10	901.9	-6.90	3.86	890.1	-6.90	3.64	877.7	-6.90	3.45	864.9
APR [illegible] AUG 25	-6.62	4.16	878.2	-6.62	3.98	872.0	-6.62	3.75	863.6	-6.62	3.54	854.2	-6.62	3.36	844.2
APR [illegible] SEP 9	-6.32	3.95	834.8	-6.32	3.84	831.7	-6.32	3.63	826.9	-6.32	3.44	820.8	-6.32	3.27	813.7
MAR [illegible] SEP [illegible]	-6.00	3.74	779.4	-6.00	3.69	780.5	-6.00	3.50	779.4	-6.00	3.33	776.5	-6.00	3.17	772.9
MAR [illegible] OCT 6	-5.68	3.75	717.4	-5.68	3.55	722.1	-5.68	3.37	724.2	-5.68	3.22	724.4	-5.68	3.08	723.1
FEB [illegible] OCT [illegible]	-5.38	3.54	653.1	-5.38	3.41	660.7	-5.38	3.25	665.7	-5.38	3.11	668.4	-5.38	2.99	669.5
FEB [illegible] NOV 9	-5.10	3.48	591.5	-5.10	3.28	601.4	-5.10	3.14	608.5	-5.10	3.01	613.3	-5.10	2.90	616.3
JAN 23 NOV 19	-4.86	3.33	539.4	-4.86	3.18	550.9	-4.86	3.05	559.4	-4.86	2.93	565.7	-4.86	2.84	570.0
JAN 10 DEC 3	-4.68	3.24	[illegible]	-4.68	3.10	513.6	-4.68	2.98	523.1	-4.68	2.87	530.4	-4.68	2.78	535.6
DEC 21	-4.57	3.19	473.6	-4.57	3.05	489.8	-4.57	2.94	501.6	-4.57	2.84	509.1	-4.57	2.75	514.7
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	[illegible]	[illegible]		[illegible]579	.5274		273.562	.5209		272.8[illegible]	.5316		271.14[illegible]	.5314	

NOTE - FOR ASPECTS [illegible] AMPLITUDE, THE TIME AND SIGN OF [illegible] AND SS ARE REVERSED.

LATITUDE 40 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 39.8		ALPHA 7.4	THETA 39.1		ALPHA 14.6	THETA 38.0		ALPHA 21.4	THETA 36.6		ALPHA 27.6	THETA 35.1		ALPHA 33.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	6.92	1020.2	-7.43	6.40	1013.1	-7.43	5.90	1002.3	-7.43	5.42	988.7	-7.43	4.98	973.4
JUN 1 JUL 12	-7.32	6.81	1001.8	-7.32	6.30	995.0	-7.32	5.80	984.8	-7.32	5.33	972.0	-7.32	4.89	957.4
MAY 18 JUL 27	-7.14	6.64	969.4	-7.14	6.13	963.3	-7.14	5.63	954.1	-7.14	5.17	942.5	-7.14	4.74	929.2
MAY 3 AUG 10	-6.90	6.40	921.7	-6.90	5.90	916.6	-6.90	5.41	908.7	-6.90	4.96	898.8	-6.90	4.54	887.3
APR 19 AUG 25	-6.62	6.12	859.2	-6.62	5.62	855.3	-6.62	5.15	849.2	-6.62	4.71	841.2	-6.62	4.31	831.9
APR 4 SEP 9	-6.32	5.82	785.3	-6.32	5.33	782.6	-6.32	4.87	778.1	-6.32	4.44	772.3	-6.32	4.06	765.3
MAR 21 SEP 23	-6.00	5.50	702.0	-6.00	5.02	700.4	-6.00	4.57	697.8	-6.00	4.16	694.1	-6.00	3.79	689.4
MAR 7 OCT 8	-5.68	5.19	615.5	-5.68	4.72	615.0	-5.68	4.28	614.0	-5.68	3.88	612.3	-5.68	3.53	609.7
FEB 20 OCT 22	-5.38	4.89	532.0	-5.38	4.42	532.5	-5.38	4.00	532.9	-5.38	3.61	532.8	-5.38	3.27	532.1
FEB 7 NOV 5	-5.10	4.61	457.0	-5.10	4.15	458.2	-5.10	3.74	459.7	-5.10	3.36	460.9	-5.10	3.04	461.6
JAN 23 NOV 19	-4.86	4.37	396.6	-4.86	3.92	398.4	-4.86	3.51	400.6	-4.86	3.15	402.7	-4.86	2.84	404.4
JAN 10 DEC 3	-4.68	4.20	354.4	-4.68	3.75	356.4	-4.68	3.35	359.1	-4.68	3.00	361.8	-4.68	2.69	364.1
DEC 22	-4.57	4.09	329.8	-4.57	3.65	332.1	-4.57	3.25	335.0	-4.57	2.90	338.0	-4.57	2.61	340.6
	YEAR 253.404		R.I. .4824	YEAR 252.648		R.I. .4807	YEAR 251.411		R.I. .4783	YEAR 249.728		R.I. .4751	YEAR 247.661		R.I. .4712

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 33.4		ALPHA 38.1	THETA 31.8		ALPHA 42.4	THETA 30.1		ALPHA 46.2	THETA 28.5		ALPHA 49.6	THETA 27.0		ALPHA 52.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.43	4.57	956.9	-7.43	4.21	940.0	-7.43	3.89	923.1	-7.43	3.61	906.6	-7.43	3.35	890.6
JUN 1 JUL 12	-7.32	4.49	941.8	-7.32	4.14	925.6	-7.32	3.82	909.4	-7.32	3.54	893.6	-7.32	3.29	878.2
MAY 18 JUL 27	-7.14	4.36	914.9	-7.14	4.01	900.0	-7.14	3.70	885.1	-7.14	3.43	870.4	-7.14	3.18	856.1
MAY 3 AUG 10	-6.90	4.17	874.8	-6.90	3.83	861.7	-6.90	3.54	848.5	-6.90	3.28	835.4	-6.90	3.04	822.6
APR 19 AUG 25	-6.62	3.95	821.5	-6.62	3.63	810.6	-6.62	3.35	799.5	-6.62	3.10	788.3	-6.62	2.87	777.2
APR 4 SEP 9	-6.32	3.71	757.3	-6.32	3.40	748.8	-6.32	3.14	739.8	-6.32	2.90	730.7	-6.32	2.69	721.6
MAR 21 SEP 23	-6.00	3.46	683.8	-6.00	3.17	677.6	-6.00	2.92	670.9	-6.00	2.69	663.9	-6.00	2.50	656.8
MAR 7 OCT 8	-5.68	3.21	606.4	-5.68	2.94	602.3	-5.68	2.70	597.7	-5.68	2.49	592.8	-5.68	2.30	587.5
FEB 20 OCT 22	-5.38	2.97	530.6	-5.38	2.71	526.4	-5.38	2.49	525.6	-5.38	2.29	522.4	-5.38	2.12	518.8
FEB 7 NOV 5	-5.10	2.75	461.6	-5.10	2.51	460.9	-5.10	2.30	459.6	-5.10	2.11	457.8	-5.10	1.95	455.5
JAN 23 NOV 19	-4.86	2.57	405.4	-4.86	2.33	405.8	-4.86	2.13	405.5	-4.86	1.96	404.7	-4.86	1.81	403.5
JAN 10 DEC 3	-4.68	2.43	365.8	-4.68	2.21	366.8	-4.68	2.01	367.2	-4.68	1.85	367.0	-4.68	1.71	366.4
DEC 22	-4.57	2.35	342.7	-4.57	2.13	344.0	-4.57	1.94	344.8	-4.57	1.78	344.9	-4.57	1.64	344.6
	YEAR 245.284		R.I. .4667	YEAR 242.681		R.I. .4617	YEAR 239.938		R.I. .4565	YEAR 237.135		R.I. .4512	YEAR 234.308		R.I. .4458

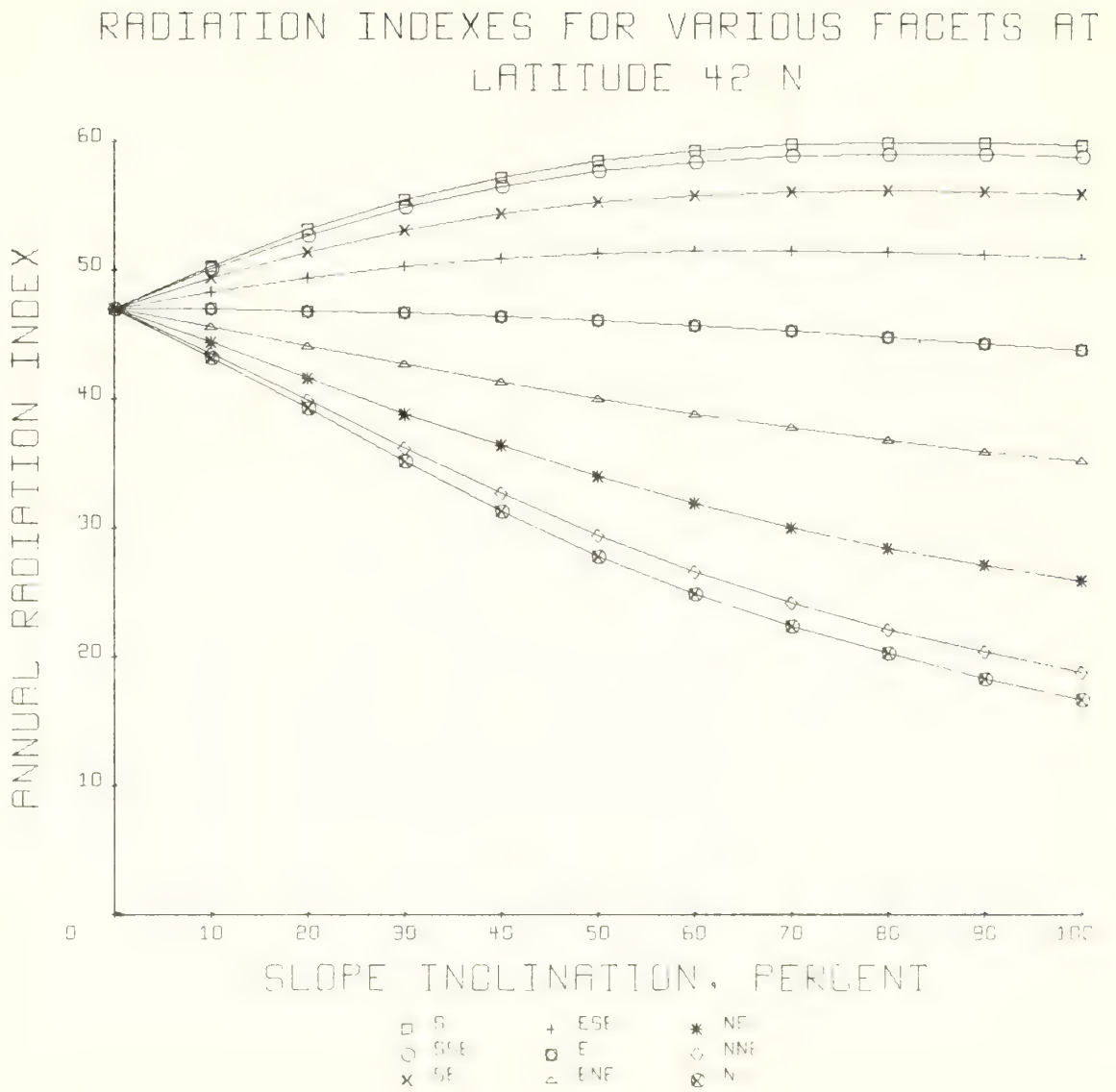
NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 42 N

		SR	SS	LY
JUN 22		-7.54	7.54	1023.7
JUN 1	JUL 12	-7.42	7.42	1003.4
MAY 18	JUL 27	-7.23	7.23	967.8
MAY 3	AUG 10	-6.97	6.97	915.8
APR 19	AUG 25	-6.67	6.67	848.6
APR 4	SEP 9	-6.34	6.34	769.5
MAR 21	SEP 23	-6.00	6.00	681.5
MAR 7	OCT 8	-5.66	5.66	591.1
FEB 20	OCT 22	-5.33	5.33	504.6
FEB 7	NOV 5	-5.03	5.03	427.6
JAN 23	NOV 19	-4.77	4.77	366.1
JAN 10	DEC 3	-4.58	4.58	323.4
DEC 22		-4.46	4.46	298.7

YEAR	R.I.
247.228	.4704



LATITUDE 42 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	47.7		0.0	53.3		0.0	58.7		0.0	63.8		0.0	68.6		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	7.54	1020.4	-7.54	7.54	1007.3	-7.54	7.54	985.7	-7.54	7.54	957.1	-7.54	7.54	923.6
JUN 1 JUL 12	-7.42	7.42	995.0	-7.42	7.42	977.2	-7.42	7.42	951.3	-7.42	7.42	919.0	-7.42	7.42	882.3
MAY 18 JUL 27	-7.23	7.23	951.1	-7.23	7.23	925.6	-7.23	7.23	892.7	-7.23	7.23	854.3	-7.23	7.23	812.3
MAY 3 AUG 10	-6.97	6.97	888.1	-6.97	6.97	852.3	-6.97	6.97	810.3	-6.97	6.97	763.8	-6.97	6.97	715.0
APR 19 AUG 25	-6.67	6.67	808.2	-6.67	6.67	760.9	-6.67	6.67	708.6	-6.67	6.67	653.3	-6.67	6.67	596.9
APR 4 SEP 9	-6.34	6.34	716.6	-6.34	6.34	657.8	-6.34	6.34	595.3	-6.34	6.34	531.3	-6.34	6.34	467.6
MAR 21 SEP 23	-6.00	6.00	617.0	-6.00	6.00	547.9	-6.00	6.00	476.5	-6.00	6.00	404.9	-6.00	6.00	335.1
MAR 7 OCT 8	-5.58	5.58	517.2	-5.49	5.49	440.2	-5.38	5.38	362.5	-5.23	5.23	286.5	-5.03	5.03	214.2
FEB 20 OCT 22	-5.18	5.18	424.3	-5.00	5.00	342.6	-4.77	4.77	262.6	-4.46	4.46	186.6	-4.04	4.04	117.5
FEB 7 NOV 5	-4.81	4.81	343.7	-4.53	4.53	260.5	-4.18	4.18	181.4	-3.70	3.70	109.7	-2.98	2.98	49.2
JAN 23 NOV 19	-4.49	4.49	280.8	-4.13	4.13	198.3	-3.65	3.65	122.5	-2.97	2.97	57.8	-1.78	1.78	10.7
JAN 10 DEC 3	-4.24	4.24	238.0	-3.81	3.81	157.2	-3.23	3.23	85.4	-2.33	2.33	28.2	0.00	0.00	0.0
DEC 22	-4.10	4.10	213.7	-3.62	3.62	134.4	-2.96	2.96	65.7	-1.86	1.86	14.4	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	227.544		.4329	206.566		.3930	185.248		.3524	164.637		.3132	146.427		.2786

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	73.0		0.0	77.0		0.0	80.7		0.0	84.0		0.0	87.0		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	7.54	887.0	-7.54	7.54	848.8	-7.54	7.54	810.5	-7.54	7.54	772.9	-7.54	7.54	736.5
JUN 1 JUL 12	-7.42	7.42	842.9	-7.42	7.42	802.5	-7.42	7.42	762.2	-7.42	7.42	723.2	-7.42	7.42	685.5
MAY 18 JUL 27	-7.23	7.23	768.5	-7.23	7.23	724.4	-7.23	7.23	681.2	-7.23	7.23	639.7	-7.23	7.23	600.1
MAY 3 AUG 10	-6.97	6.97	665.4	-6.97	6.97	616.6	-6.97	6.97	569.6	-6.97	6.97	525.0	-6.97	6.97	482.9
APR 19 AUG 25	-6.67	6.67	541.1	-6.67	6.67	487.2	-6.67	6.67	436.1	-6.67	6.67	388.4	-6.67	6.67	343.7
APR 4 SEP 9	-6.34	6.34	406.0	-6.34	6.34	347.4	-6.34	6.34	292.6	-6.34	6.34	242.0	-6.34	6.34	195.3
MAR 21 SEP 23	-6.00	6.00	268.6	-6.00	6.00	206.3	-6.00	6.00	148.8	-6.00	6.00	96.2	-6.00	6.00	48.0
MAR 7 OCT 8	-4.75	4.75	147.3	-4.31	4.31	87.3	-3.54	3.54	36.4	-1.38	1.38	1.5	0.00	0.00	0.0
FEB 20 OCT 22	-3.40	3.40	58.1	-2.22	2.22	13.1	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
FEB 7 NOV 5	-1.63	1.63	6.7	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	131.205		.2496	118.067		.2246	106.690		.2030	96.681		.1839	88.142		.1677

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LAYITUDE 42 N
ASPECT S -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 36.3		ALPHA 0.0	THETA 30.7		ALPHA 0.0	THETA 25.3		ALPHA 0.0	THETA 20.2		ALPHA 0.0	THETA 15.4		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.24	7.24	1018.7	-7.00	7.00	1007.0	-6.79	6.79	989.0	-6.61	6.61	965.5	-6.46	6.46	938.1
JUN 1 JUL 12	-7.15	7.15	1003.4	-6.92	6.92	996.3	-6.73	6.73	982.5	-6.57	6.57	962.9	-6.43	6.43	938.9
MAY 18 JUL 27	-7.00	7.00	976.1	-6.80	6.80	976.7	-6.64	6.64	970.1	-6.49	6.49	957.1	-6.37	6.37	939.0
MAY 3 AUG 10	-6.79	6.79	935.2	-6.64	6.64	946.5	-6.51	6.51	949.8	-6.39	6.39	945.9	-6.29	6.29	936.2
APR 19 AUG 25	-6.54	6.54	880.8	-6.44	6.44	904.5	-6.35	6.35	919.7	-6.27	6.27	926.9	-6.20	6.20	927.3
APR 4 SEP 9	-6.28	6.28	815.0	-6.22	6.22	851.8	-6.18	6.18	879.6	-6.14	6.14	898.9	-6.10	6.10	910.6
MAR 21 SEP 23	-6.00	6.00	739.3	-6.00	6.00	788.7	-6.00	6.00	829.1	-6.00	6.00	860.7	-6.00	6.00	884.0
MAR 7 OCT 8	-5.66	5.66	659.2	-5.66	5.66	719.5	-5.66	5.66	771.1	-5.66	5.66	813.6	-5.66	5.66	847.6
FEB 20 OCT 22	-5.33	5.33	580.4	-5.33	5.33	649.0	-5.33	5.33	709.2	-5.33	5.33	760.4	-5.33	5.33	802.8
FEB 7 NOV 5	-5.03	5.03	508.3	-5.03	5.03	582.4	-5.03	5.03	648.5	-5.03	5.03	705.8	-5.03	5.03	754.3
JAN 23 NOV 19	-4.77	4.77	449.4	-4.77	4.77	526.6	-4.77	4.77	596.2	-4.77	4.77	657.2	-4.77	4.77	709.5
JAN 10 DEC 3	-4.58	4.58	407.7	-4.58	4.58	486.3	-4.58	4.58	557.5	-4.58	4.58	620.4	-4.58	4.58	674.8
DEC 22	-4.46	4.46	383.2	-4.46	4.46	462.3	-4.46	4.46	534.2	-4.46	4.46	597.9	-4.46	4.46	653.2
	YEAR 264.826		R.I. .5039	YEAR 279.785		R.I. .5323	YEAR 291.858		R.I. .5553	YEAR 301.081		R.I. .5728	YEAR 307.673		R.I. .5854

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 11.0		ALPHA 0.0	THETA 7.0		ALPHA 0.0	THETA 3.3		ALPHA 0.0	THETA 0.0		ALPHA 0.0	THETA -3.0		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.32	6.32	908.1	-6.20	6.20	876.7	-6.10	6.10	845.1	-6.00	6.00	814.0	-5.91	5.91	783.9
JUN 1 JUL 12	-6.30	6.30	912.0	-6.19	6.19	883.2	-6.09	6.09	853.9	-6.00	6.00	824.8	-5.92	5.92	796.4
MAY 18 JUL 27	-6.26	6.26	917.2	-6.16	6.16	893.1	-6.08	6.08	867.8	-6.00	6.00	842.2	-5.93	5.93	816.8
MAY 3 AUG 10	-6.21	6.21	921.8	-6.13	6.13	904.3	-6.06	6.06	884.8	-6.00	6.00	864.2	-5.94	5.94	843.2
APR 19 AUG 25	-6.14	6.14	922.2	-6.09	6.09	913.0	-6.04	6.04	900.8	-6.00	6.00	886.7	-5.96	5.96	871.4
APR 4 SEP 9	-6.07	6.07	915.9	-6.05	6.05	916.0	-6.02	6.02	912.3	-6.00	6.00	905.7	-5.98	5.98	897.0
MAR 21 SEP 23	-6.00	6.00	900.1	-6.00	6.00	910.3	-6.00	6.00	915.5	-6.00	6.00	917.1	-6.00	6.00	915.8
MAR 7 OCT 8	-5.66	5.66	873.8	-5.66	5.66	893.2	-5.66	5.66	907.1	-5.66	5.66	916.4	-5.66	5.66	922.2
FEB 20 OCT 22	-5.33	5.33	837.0	-5.33	5.33	864.1	-5.33	5.33	885.0	-5.33	5.33	900.8	-5.33	5.33	912.5
FEB 7 NOV 5	-5.03	5.03	794.4	-5.03	5.03	827.1	-5.03	5.03	853.3	-5.03	5.03	874.0	-5.03	5.03	890.2
JAN 23 NOV 19	-4.77	4.77	753.5	-4.77	4.77	789.9	-4.77	4.77	819.6	-4.77	4.77	843.5	-4.77	4.77	862.9
JAN 10 DEC 3	-4.58	4.58	720.9	-4.58	4.58	759.4	-4.58	4.58	791.1	-4.58	4.58	817.0	-4.58	4.58	838.2
DEC 22	-4.46	4.46	700.2	-4.46	4.46	739.7	-4.46	4.46	772.5	-4.46	4.46	799.4	-4.46	4.46	821.5
	YEAR 311.967		R.I. .5935	YEAR 314.367		R.I. .5981	YEAR 315.260		R.I. .5998	YEAR 315.007		R.I. .5993	YEAR 313.901		R.I. .5972

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 42 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	47.2		3.2	52.3		7.0	57.0		11.6	61.2		17.2	64.9		23.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	7.54	1020.3	-7.54	7.54	1007.1	-7.54	7.54	985.3	-7.54	7.54	956.6	-7.54	7.54	923.0
JUN 1 JUL 12	-7.42	7.42	995.3	-7.42	7.42	977.7	-7.42	7.42	952.0	-7.42	7.42	920.0	-7.42	7.42	883.4
MAY 18 JUL 27	-7.23	7.23	952.0	-7.23	7.23	927.4	-7.23	7.23	895.3	-7.23	7.23	857.7	-7.23	7.23	816.4
MAY 3 AUG 10	-6.97	6.96	889.8	-6.97	6.94	855.8	-6.97	6.92	815.4	-6.97	6.89	770.5	-6.97	6.85	723.0
APR 19 AUG 25	-6.67	6.59	811.0	-6.67	6.49	766.6	-6.67	6.37	717.2	-6.67	6.23	664.8	-6.67	6.03	611.5
APR 4 SEP 9	-6.34	6.19	720.5	-6.34	6.02	666.1	-6.34	5.81	608.5	-6.34	5.55	549.8	-6.34	5.22	492.2
MAR 21 SEP 23	-6.00	5.79	622.2	-6.00	5.53	559.2	-6.00	5.22	495.0	-6.00	4.86	432.1	-6.00	4.41	372.6
MAR 7 OCT 8	-5.66	5.38	523.4	-5.66	5.04	454.0	-5.66	4.64	385.7	-5.66	4.17	320.9	-5.66	3.60	262.0
FEB 20 OCT 22	-5.33	4.98	431.1	-5.33	4.57	357.9	-5.33	4.07	288.0	-5.33	3.49	224.0	-5.33	2.79	168.2
FEB 7 NOV 5	-5.03	4.62	350.7	-5.03	4.12	276.1	-5.03	3.53	206.8	-5.03	2.82	145.7	-5.03	1.98	94.9
JAN 23 NOV 19	-4.73	4.30	287.9	-4.67	3.73	213.6	-4.60	3.05	146.6	-4.50	2.21	89.7	-4.35	1.18	45.4
JAN 10 DEC 3	-4.49	4.06	245.1	-4.38	3.44	172.0	-4.22	2.67	107.8	-4.00	1.71	55.6	-3.62	.45	18.3
DEC 22	-4.34	3.92	220.7	-4.19	3.25	148.8	-3.98	2.43	86.8	-3.66	1.37	38.2	-3.04	-.13	6.7
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	229.095		.4359	209.900		.3994	190.532		.3625	171.848		.3270	154.690		.2943

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	68.0		31.7	70.4		40.8	72.1		50.9	73.1		61.5	73.5		71.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	7.54	886.3	-7.54	7.54	848.0	-7.54	7.54	809.6	-7.54	7.54	772.0	-7.54	7.54	735.5
JUN 1 JUL 12	-7.42	7.42	844.2	-7.42	7.42	803.9	-7.42	7.42	763.8	-7.42	7.42	724.9	-7.42	7.42	687.3
MAY 18 JUL 27	-7.23	7.23	773.2	-7.23	7.23	729.6	-7.23	7.23	686.9	-7.23	7.23	645.8	-7.23	7.23	606.5
MAY 3 AUG 10	-6.97	6.79	674.7	-6.97	6.71	627.0	-6.97	6.57	581.0	-6.97	6.32	537.5	-6.97	5.87	496.7
APR 19 AUG 25	-6.67	5.79	559.0	-6.67	5.46	508.8	-6.67	5.04	462.1	-6.67	4.52	419.8	-6.67	3.91	382.2
APR 4 SEP 9	-6.34	4.83	437.6	-6.34	4.35	387.3	-6.34	3.79	342.6	-6.34	3.16	304.0	-6.34	2.50	271.4
MAR 21 SEP 23	-6.00	3.89	318.3	-6.00	3.28	270.5	-6.00	2.60	230.2	-6.00	1.90	197.2	-6.00	1.21	171.0
MAR 7 OCT 8	-5.66	2.95	210.7	-5.66	2.21	167.9	-5.66	1.42	134.0	-5.66	.64	108.4	-5.66	-.09	89.5
FEB 20 OCT 22	-5.33	1.99	122.1	-5.33	1.10	86.4	-5.33	.17	60.7	-5.33	-.72	43.4	-5.33	-1.49	32.3
FEB 7 NOV 5	-5.03	.98	56.0	-5.03	-.15	29.2	-5.03	-1.36	13.2	-5.03	-2.52	5.4	-5.03	-3.46	2.3
JAN 23 NOV 19	-4.10	-.12	15.3	-3.40	-2.04	.6	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	-2.40	-1.82	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	139.904		.2662	127.384		.2424	116.638		.2219	107.306		.2042	99.182		.1887

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 42 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	36.7	2.7		31.4	5.0		26.3	7.0		21.5	8.8		16.9	10.3	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.44	7.08	1019.3	-7.36	6.69	1009.0	-7.30	6.36	993.0	-7.24	6.07	972.0	-7.19	5.82	947.4
JUN 1 JUL 12	-7.35	6.98	1003.6	-7.29	6.61	997.6	-7.24	6.30	985.7	-7.19	6.02	968.5	-7.16	5.78	947.1
MAY 18 JUL 27	-7.19	6.83	975.7	-7.16	6.49	977.1	-7.14	6.20	971.9	-7.11	5.94	961.0	-7.10	5.72	945.4
MAY 3 AUG 10	-6.97	6.62	934.1	-6.97	6.32	945.5	-6.97	6.06	949.7	-6.97	5.83	947.5	-6.97	5.64	939.9
APR 19 AUG 25	-6.67	6.37	878.8	-6.67	6.11	901.7	-6.67	5.90	917.0	-6.67	5.70	925.1	-6.67	5.54	927.0
APR 4 SEP 9	-6.34	6.10	811.8	-6.34	5.89	846.7	-6.34	5.72	873.4	-6.34	5.56	892.5	-6.34	5.43	904.4
MAR 21 SEP 23	-6.00	5.82	735.0	-6.00	5.66	781.1	-6.00	5.53	818.8	-6.00	5.41	848.3	-6.00	5.31	870.2
MAR 7 OCT 8	-5.66	5.54	654.0	-5.66	5.43	709.6	-5.66	5.34	756.9	-5.66	5.27	795.8	-5.66	5.20	826.6
FEB 20 OCT 22	-5.33	5.27	574.5	-5.33	5.21	637.5	-5.33	5.16	692.4	-5.33	5.12	738.8	-5.33	5.09	777.0
FEB 7 NOV 5	-5.03	5.02	502.0	-5.03	5.01	570.0	-5.03	5.00	630.3	-5.03	4.99	682.3	-5.03	4.99	726.0
JAN 23 NOV 19	-4.77	4.77	442.9	-4.77	4.77	513.9	-4.77	4.77	577.5	-4.77	4.77	633.0	-4.77	4.77	680.4
JAN 10 DEC 3	-4.58	4.58	401.1	-4.58	4.58	473.4	-4.58	4.58	538.6	-4.58	4.58	596.0	-4.58	4.58	645.5
DEC 22	-4.46	4.46	376.7	-4.46	4.46	449.4	-4.46	4.46	515.3	-4.46	4.46	573.5	-4.46	4.46	623.8
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	263.524	.5014		277.427	.5278		288.674	.5492		297.274	.5656		303.418	.5773	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	12.7	11.6		8.9	12.8		5.4	13.9		2.2	14.8		-0.7	15.7	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.15	5.60	920.2	-7.12	5.40	891.8	-7.08	5.23	862.9	-7.05	5.07	834.6	-7.03	4.93	807.0
JUN 1 JUL 12	-7.13	5.57	923.0	-7.10	5.39	897.1	-7.07	5.22	870.5	-7.05	5.07	844.1	-7.03	4.93	818.2
MAY 18 JUL 27	-7.08	5.53	926.2	-7.07	5.35	904.8	-7.05	5.20	882.2	-7.04	5.06	859.2	-7.03	4.94	836.3
MAY 3 AUG 10	-6.97	5.46	927.9	-6.97	5.31	912.9	-6.97	5.17	896.0	-6.97	5.05	877.9	-6.97	4.94	859.3
APR 19 AUG 25	-6.67	5.39	923.7	-6.67	5.26	916.4	-6.67	5.14	906.3	-6.67	5.04	894.3	-6.67	4.94	881.1
APR 4 SEP 9	-6.34	5.31	910.4	-6.34	5.20	911.5	-6.34	5.11	908.8	-6.34	5.02	903.5	-6.34	4.95	896.2
MAR 21 SEP 23	-6.00	5.22	885.3	-6.00	5.14	894.8	-6.00	5.07	899.7	-6.00	5.01	901.1	-6.00	4.95	899.9
MAR 7 OCT 8	-5.66	5.14	850.0	-5.66	5.09	867.2	-5.66	5.04	879.2	-5.66	5.00	887.0	-5.66	4.96	891.6
FEB 20 OCT 22	-5.33	5.06	807.4	-5.33	5.03	831.2	-5.33	5.00	849.3	-5.33	4.98	862.7	-5.33	4.96	872.4
FEB 7 NOV 5	-5.03	4.98	761.9	-5.03	4.98	790.9	-5.03	4.97	813.8	-5.03	4.97	831.7	-5.03	4.97	845.5
JAN 23 NOV 19	-4.77	4.77	720.0	-4.77	4.77	752.6	-4.77	4.77	778.9	-4.77	4.77	800.0	-4.77	4.77	816.9
JAN 10 DEC 3	-4.58	4.58	687.1	-4.58	4.58	721.7	-4.58	4.58	750.1	-4.58	4.58	773.1	-4.58	4.58	791.8
DEC 22	-4.46	4.46	666.4	-4.46	4.46	702.1	-4.46	4.46	731.4	-4.46	4.46	755.4	-4.46	4.46	775.1
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	307.408	.5849		309.621	.5891		310.418	.5906		310.136	.5901		309.056	.5880	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 42 N
ASPECT NE - NW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 45.9		ALPHA 5.8	THETA 49.4		ALPHA 12.3	THETA 52.4		ALPHA 19.4	THETA 54.7		ALPHA 27.0	THETA 56.5		ALPHA 34.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	7.39	1020.1	-7.54	7.21	1007.1	-7.54	6.99	986.2	-7.54	6.73	959.1	-7.54	6.40	928.0
JUN 1 JUL 12	-7.42	7.25	996.2	-7.42	7.05	980.2	-7.42	6.81	956.8	-7.42	6.51	927.9	-7.42	6.17	895.5
MAY 18 JUL 27	-7.23	7.03	955.0	-7.23	6.79	934.1	-7.23	6.51	906.7	-7.23	6.18	874.6	-7.23	5.80	840.4
MAY 3 AUG 10	-6.97	6.73	895.4	-6.97	6.45	868.2	-6.97	6.12	835.8	-6.97	5.74	800.3	-6.97	5.33	763.8
APR 19 AUG 25	-6.67	6.38	819.7	-6.67	6.05	785.4	-6.67	5.67	747.8	-6.67	5.25	708.8	-6.67	4.80	670.4
APR 4 SEP 9	-6.34	6.00	732.2	-6.34	5.62	691.3	-6.34	5.19	648.9	-6.34	4.73	607.1	-6.34	4.24	567.6
MAR 21 SEP 23	-6.00	5.61	636.6	-6.00	5.18	590.0	-6.00	4.70	544.1	-6.00	4.20	500.6	-6.00	3.67	461.1
MAR 7 OCT 8	-5.66	5.22	540.0	-5.66	4.74	489.3	-5.66	4.21	441.3	-5.66	3.66	397.6	-5.66	3.10	359.3
FEB 20 OCT 22	-5.33	4.85	449.3	-5.33	4.31	396.3	-5.33	3.74	347.7	-5.33	3.14	305.1	-5.33	2.54	269.1
FEB 7 NOV 5	-5.03	4.50	369.9	-5.03	3.91	316.2	-5.03	3.29	268.4	-5.03	2.65	227.9	-5.03	2.01	194.9
JAN 23 NOV 19	-4.77	4.20	307.5	-4.77	3.57	254.1	-4.77	2.90	208.0	-4.77	2.21	170.0	-4.77	1.54	140.2
JAN 10 DEC 3	-4.58	3.97	264.7	-4.58	3.31	212.2	-4.58	2.60	167.8	-4.58	1.88	132.1	-4.58	1.17	104.9
DEC 22	-4.46	3.84	240.2	-4.46	3.15	188.5	-4.46	2.42	145.3	-4.46	1.67	111.2	-4.46	.94	85.8
	YEAR 233.449		R.I. .4442	YEAR 219.094		R.I. .4168	YEAR 204.853		R.I. .3898	YEAR 191.294		R.I. .3640	YEAR 178.843		R.I. .3403

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 57.6		ALPHA 42.7	THETA 58.2		ALPHA 50.2	THETA 58.3		ALPHA 57.2	THETA 58.1		ALPHA 63.5	THETA 57.6		ALPHA 69.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	6.03	895.0	-7.54	5.61	861.7	-7.54	5.17	829.6	-7.54	4.72	799.6	-7.54	4.28	772.0
JUN 1 JUL 12	-7.42	5.78	861.7	-7.42	5.35	828.1	-7.42	4.90	796.2	-7.42	4.46	766.6	-7.42	4.03	739.5
MAY 18 JUL 27	-7.23	5.39	805.6	-7.23	4.94	771.8	-7.23	4.49	740.2	-7.23	4.05	711.4	-7.23	3.63	685.3
MAY 3 AUG 10	-6.97	4.89	728.0	-6.97	4.43	694.2	-6.97	3.98	663.3	-6.97	3.54	635.6	-6.97	3.13	611.0
APR 19 AUG 25	-6.67	4.33	634.1	-6.67	3.86	600.9	-6.67	3.40	571.3	-6.67	2.97	545.3	-6.67	2.57	522.6
APR 4 SEP 9	-6.34	3.75	531.6	-6.34	3.26	499.7	-6.34	2.80	472.0	-6.34	2.37	448.2	-6.34	1.99	427.9
MAR 21 SEP 23	-6.00	3.15	426.4	-6.00	2.65	396.6	-6.00	2.19	371.5	-6.00	1.77	350.6	-6.00	1.39	333.0
MAR 7 OCT 8	-5.66	2.56	326.8	-5.66	2.04	299.9	-5.66	1.57	277.9	-5.66	1.16	260.1	-5.66	.80	245.5
FEB 20 OCT 22	-5.33	1.97	239.7	-5.33	1.44	216.1	-5.33	.97	197.6	-5.33	.56	182.9	-5.33	.21	171.3
FEB 7 NOV 5	-5.03	1.41	169.0	-5.03	.87	149.0	-5.03	.40	133.8	-5.03	-.01	122.3	-5.03	-.35	113.3
JAN 23 NOV 19	-4.77	.92	117.6	-4.77	.36	100.9	-4.77	-.12	88.7	-4.77	-.52	79.8	-4.77	-.85	73.1
JAN 10 DEC 3	-4.58	.52	85.1	-4.58	-.05	70.9	-4.58	-.53	61.0	-4.58	-.92	53.9	-4.58	-1.24	48.8
DEC 22	-4.46	.27	67.7	-4.46	-.31	55.1	-4.46	-.80	46.5	-4.46	-1.19	40.6	-4.46	-1.50	36.4
	YEAR 167.735		R.I. .3191	YEAR 158.012		R.I. .3006	YEAR 149.625		R.I. .2847	YEAR 142.447		R.I. .2710	YEAR 136.265		R.I. .2593

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 42 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	37.8		5.1	33.6		9.6	29.3		13.5	25.2		16.9	21.3		19.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	6.97	1020.6	-7.54	6.48	1013.4	-7.54	6.04	1002.0	-7.54	5.66	986.9	-7.54	5.33	968.7
JUN 1 JUL 12	-7.42	6.88	1003.9	-7.42	6.40	1000.1	-7.42	5.97	992.0	-7.42	5.61	979.8	-7.42	5.28	964.4
MAY 18 JUL 27	-7.23	6.71	974.2	-7.23	6.26	976.2	-7.23	5.86	973.5	-7.23	5.51	966.3	-7.23	5.20	955.4
MAY 3 AUG 10	-6.97	6.49	930.2	-6.97	6.07	939.9	-6.97	5.70	944.4	-6.97	5.38	944.0	-6.97	5.09	939.2
APR 19 AUG 25	-6.67	6.23	872.1	-6.67	5.85	890.6	-6.67	5.52	903.5	-6.67	5.22	910.9	-6.67	4.96	913.3
APR 4 SEP 9	-6.34	5.95	802.3	-6.34	5.61	829.8	-6.34	5.31	851.4	-6.34	5.05	867.0	-6.34	4.82	876.9
MAR 21 SEP 23	-6.00	5.66	722.8	-6.00	5.36	758.8	-6.00	5.10	788.5	-6.00	4.88	811.8	-6.00	4.68	829.0
MAR 7 OCT 8	-5.66	5.37	639.4	-5.66	5.11	682.5	-5.66	4.89	719.2	-5.66	4.70	749.3	-5.66	4.53	772.9
FEB 20 OCT 22	-5.33	5.08	558.2	-5.33	4.87	606.6	-5.33	4.69	648.7	-5.33	4.53	684.1	-5.33	4.39	712.9
FEB 7 NOV 5	-5.03	4.82	484.6	-5.03	4.65	536.5	-5.03	4.50	582.3	-5.03	4.37	621.4	-5.03	4.26	653.9
JAN 23 NOV 19	-4.77	4.60	424.8	-4.77	4.46	478.7	-4.77	4.34	526.7	-4.77	4.24	568.1	-4.77	4.15	603.0
JAN 10 DEC 3	-4.58	4.44	382.7	-4.58	4.33	437.5	-4.58	4.23	486.5	-4.58	4.14	529.2	-4.58	4.07	565.5
DEC 22	-4.46	4.34	358.2	-4.46	4.24	413.3	-4.46	4.16	462.7	-4.46	4.09	505.9	-4.46	4.03	542.8
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	259.771		.4942	270.563		.5148	279.321		.5314	286.000		.5441	290.715		.5531

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	17.7		22.4	14.3		24.7	11.2		26.8	8.4		28.6	5.8		30.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	5.03	948.4	-7.54	4.77	926.8	-7.54	4.54	904.7	-7.54	4.34	882.7	-7.54	4.16	861.2
JUN 1 JUL 12	-7.42	5.00	946.6	-7.42	4.74	927.0	-7.42	4.52	906.8	-7.42	4.32	886.5	-7.42	4.15	866.3
MAY 18 JUL 27	-7.23	4.93	941.5	-7.23	4.69	925.6	-7.23	4.48	908.6	-7.23	4.29	891.0	-7.23	4.13	873.3
MAY 3 AUG 10	-6.97	4.84	930.9	-6.97	4.62	919.9	-6.97	4.43	907.2	-6.97	4.25	893.4	-6.97	4.10	879.0
APR 19 AUG 25	-6.67	4.74	911.5	-6.67	4.54	906.4	-6.67	4.36	898.8	-6.67	4.20	889.6	-6.67	4.06	879.3
APR 4 SEP 9	-6.34	4.62	882.0	-6.34	4.45	883.1	-6.34	4.29	881.0	-6.34	4.15	876.7	-6.34	4.03	870.8
MAR 21 SEP 23	-6.00	4.50	840.8	-6.00	4.35	848.0	-6.00	4.22	851.4	-6.00	4.10	852.1	-6.00	3.99	850.6
MAR 7 OCT 8	-5.66	4.38	790.6	-5.66	4.25	803.4	-5.66	4.14	811.9	-5.66	4.04	817.1	-5.66	3.95	819.7
FEB 20 OCT 22	-5.33	4.27	735.5	-5.33	4.16	752.8	-5.33	4.07	765.6	-5.33	3.99	774.7	-5.33	3.91	780.9
FEB 7 NOV 5	-5.03	4.16	680.2	-5.03	4.08	701.0	-5.03	4.00	717.1	-5.03	3.94	729.5	-5.03	3.88	738.3
JAN 23 NOV 19	-4.77	4.08	631.8	-4.77	4.01	655.0	-4.77	3.95	673.3	-4.77	3.90	687.7	-4.77	3.85	698.8
JAN 10 DEC 3	-4.58	4.01	595.6	-4.58	3.96	620.2	-4.58	3.91	640.0	-4.58	3.87	655.7	-4.58	3.83	668.1
DEC 22	-4.46	3.97	573.6	-4.46	3.93	598.9	-4.46	3.89	619.4	-4.46	3.85	635.8	-4.46	3.82	648.9
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	293.692		.5588	295.226		.5617	295.608		.5624	295.115		.5615	293.972		.5593

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	44.0		7.3	45.4		15.0	46.3		22.6	46.6		30.0	46.5		36.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	7.16	1020.6	-7.54	6.75	1010.5	-7.54	6.30	994.9	-7.54	5.83	975.6	-7.54	5.36	954.1
JUN 1 JUL 12	-7.42	7.04	998.5	-7.42	6.61	987.0	-7.42	6.16	970.6	-7.42	5.69	950.8	-7.42	5.22	929.3
MAY 18 JUL 27	-7.23	6.83	960.0	-7.23	6.39	946.4	-7.23	5.93	928.7	-7.23	5.46	908.3	-7.23	4.99	886.7
MAY 3 AUG 10	-6.97	6.55	904.2	-6.97	6.10	887.9	-6.97	5.62	868.5	-6.97	5.15	847.3	-6.97	4.68	825.7
APR 19 AUG 25	-6.67	6.22	832.6	-6.67	5.75	813.4	-6.67	5.27	792.3	-6.67	4.79	770.5	-6.67	4.32	749.1
APR 4 SEP 9	-6.34	5.87	749.3	-6.34	5.39	727.3	-6.34	4.89	704.7	-6.34	4.40	682.7	-6.34	3.94	661.8
MAR 21 SEP 23	-6.00	5.51	657.5	-6.00	5.00	633.1	-6.00	4.49	609.6	-6.00	4.00	587.7	-6.00	3.54	567.8
MAR 7 OCT 8	-5.66	5.15	563.9	-5.66	4.62	538.0	-5.66	4.10	514.1	-5.66	3.60	492.8	-5.66	3.14	474.2
FEB 20 OCT 22	-5.33	4.80	475.4	-5.33	4.25	448.6	-5.33	3.72	425.0	-5.33	3.22	404.7	-5.33	2.76	387.5
FEB 7 NOV 5	-5.03	4.47	397.2	-5.03	3.91	370.3	-5.03	3.36	347.4	-5.03	2.86	328.3	-5.03	2.40	312.8
JAN 23 NOV 19	-4.77	4.19	335.3	-4.77	3.61	308.7	-4.77	3.06	286.7	-4.77	2.55	268.9	-4.77	2.09	254.8
JAN 10 DEC 3	-4.58	3.98	292.6	-4.58	3.39	266.5	-4.58	2.83	245.3	-4.58	2.32	228.6	-4.58	1.86	215.6
DEC 22	-4.46	3.86	268.0	-4.46	3.26	242.3	-4.46	2.69	221.8	-4.46	2.17	205.7	-4.46	1.72	193.4
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	239.794		.4562	232.103		.4416	224.505		.4271	217.249		.4133	210.495		.4005

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	46.1		43.2	45.3		48.9	44.4		53.9	43.4		58.3	42.4		62.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	4.91	932.0	-7.54	4.48	910.1	-7.54	4.09	889.1	-7.54	3.73	869.4	-7.54	3.41	850.9
JUN 1 JUL 12	-7.42	4.77	907.3	-7.42	4.34	885.8	-7.42	3.96	865.2	-7.42	3.61	845.9	-7.42	3.29	827.8
MAY 18 JUL 27	-7.23	4.54	865.0	-7.23	4.12	843.9	-7.23	3.75	824.0	-7.23	3.40	805.5	-7.23	3.10	788.3
MAY 3 AUG 10	-6.97	4.24	804.5	-6.97	3.83	784.4	-6.97	3.46	765.5	-6.97	3.13	748.1	-6.97	2.84	732.1
APR 19 AUG 25	-6.67	3.89	728.7	-6.67	3.49	709.7	-6.67	3.13	692.3	-6.67	2.81	676.3	-6.67	2.53	661.7
APR 4 SEP 9	-6.34	3.51	642.6	-6.34	3.12	625.0	-6.34	2.77	609.2	-6.34	2.47	594.9	-6.34	2.20	582.0
MAR 21 SEP 23	-6.00	3.12	550.0	-6.00	2.74	534.1	-6.00	2.40	520.1	-6.00	2.11	507.7	-6.00	1.85	496.6
MAR 7 OCT 8	-5.66	2.73	458.0	-5.66	2.36	444.0	-5.66	2.03	431.9	-5.66	1.75	421.4	-5.66	1.51	412.1
FEB 20 OCT 22	-5.33	2.35	373.1	-5.33	1.99	361.0	-5.33	1.68	350.8	-5.33	1.41	342.0	-5.33	1.18	334.4
FEB 7 NOV 5	-5.03	2.00	300.1	-5.03	1.65	289.7	-5.03	1.35	281.1	-5.03	1.09	273.9	-5.03	.87	267.8
JAN 23 NOV 19	-4.77	1.69	243.6	-4.77	1.35	234.7	-4.77	1.06	227.5	-4.77	.82	221.5	-4.77	.61	216.4
JAN 10 DEC 3	-4.58	1.47	205.5	-4.58	1.13	197.6	-4.58	.85	191.3	-4.58	.61	186.2	-4.58	.41	181.9
DEC 22	-4.46	1.33	184.0	-4.46	1.00	176.6	-4.46	.72	170.9	-4.46	.49	166.3	-4.46	.29	162.4
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	204.318		.3887	198.717		.3781	193.672		.3685	189.138		.3599	185.026		.3520

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 42 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	39.6		6.9	36.9		13.1	34.0		18.7	31.0		23.6	28.1		27.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	6.95	1021.4	-7.54	6.40	1015.6	-7.54	5.89	1006.8	-7.54	5.44	995.1	-7.54	5.03	981.1
JUN 1 JUL 12	-7.42	6.84	1003.0	-7.42	6.30	999.4	-7.42	5.81	992.5	-7.42	5.36	982.8	-7.42	4.97	970.6
MAY 18 JUL 27	-7.23	6.67	970.8	-7.23	6.14	970.6	-7.23	5.67	967.0	-7.23	5.24	960.5	-7.23	4.86	951.3
MAY 3 AUG 10	-6.97	6.43	923.3	-6.97	5.93	927.6	-6.97	5.48	928.6	-6.97	5.07	926.3	-6.97	4.71	921.1
APR 19 AUG 25	-6.67	6.15	861.2	-6.67	5.68	870.7	-6.67	5.25	876.9	-6.67	4.87	879.6	-6.67	4.53	879.0
APR 4 SEP 9	-6.34	5.85	787.3	-6.34	5.41	802.2	-6.34	5.01	813.7	-6.34	4.65	821.5	-6.34	4.34	825.7
MAR 21 SEP 23	-6.00	5.54	704.1	-6.00	5.13	723.9	-6.00	4.75	740.3	-6.00	4.43	752.9	-6.00	4.14	761.7
MAR 7 OCT 8	-5.66	5.23	617.6	-5.66	4.84	641.5	-5.66	4.50	662.1	-5.66	4.20	678.8	-5.66	3.94	691.6
FEB 20 OCT 22	-5.33	4.93	534.0	-5.33	4.57	561.1	-5.33	4.26	584.8	-5.33	3.98	604.7	-5.33	3.74	620.6
FEB 7 NOV 5	-5.03	4.65	458.8	-5.03	4.32	487.9	-5.03	4.03	513.7	-5.03	3.78	535.8	-5.03	3.57	553.9
JAN 23 NOV 19	-4.77	4.42	398.3	-4.77	4.11	428.4	-4.77	3.84	455.4	-4.77	3.61	478.7	-4.77	3.42	498.2
JAN 10 DEC 3	-4.58	4.24	355.9	-4.58	3.95	386.5	-4.58	3.70	414.0	-4.58	3.49	437.9	-4.58	3.31	458.1
DEC 22	-4.46	4.14	331.3	-4.46	3.86	362.0	-4.46	3.62	389.7	-4.46	3.41	413.8	-4.46	3.24	434.3
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	254.024		.4833	259.843		.4944	264.468		.5032	267.824		.5096	269.954		.5136

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	25.3		31.7	22.6		35.0	20.2		37.9	17.9		40.5	15.8		42.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	4.68	965.5	-7.54	4.36	948.9	-7.54	4.08	931.8	-7.54	3.84	914.7	-7.54	3.62	897.9
JUN 1 JUL 12	-7.42	4.62	956.6	-7.42	4.31	941.4	-7.42	4.04	925.6	-7.42	3.80	909.7	-7.42	3.59	893.9
MAY 18 JUL 27	-7.23	4.52	940.0	-7.23	4.22	927.2	-7.23	3.96	913.6	-7.23	3.73	899.6	-7.23	3.53	885.5
MAY 3 AUG 10	-6.97	4.39	913.5	-6.97	4.11	904.1	-6.97	3.86	893.4	-6.97	3.64	882.1	-6.97	3.45	870.3
APR 19 AUG 25	-6.67	4.23	875.7	-6.67	3.97	870.2	-6.67	3.74	863.0	-6.67	3.54	854.7	-6.67	3.36	845.7
APR 4 SEP 9	-6.34	4.06	826.9	-6.34	3.82	825.4	-6.34	3.61	821.9	-6.34	3.42	817.0	-6.34	3.26	811.0
MAR 21 SEP 23	-6.00	3.89	767.2	-6.00	3.66	769.7	-6.00	3.47	769.9	-6.00	3.30	766.2	-6.00	3.15	765.2
MAR 7 OCT 8	-5.66	3.71	700.8	-5.66	3.51	706.9	-5.66	3.33	710.3	-5.66	3.18	711.7	-5.66	3.04	711.5
FEB 20 OCT 22	-5.33	3.54	632.8	-5.33	3.36	641.7	-5.33	3.20	647.9	-5.33	3.06	651.7	-5.33	2.94	653.8
FEB 7 NOV 5	-5.03	3.38	568.3	-5.03	3.22	579.3	-5.03	3.08	587.5	-5.03	2.96	593.3	-5.03	2.85	597.2
JAN 23 NOV 19	-4.77	3.25	514.0	-4.77	3.10	526.4	-4.77	2.98	535.9	-4.77	2.87	543.0	-4.77	2.77	548.2
JAN 10 DEC 3	-4.58	3.15	474.6	-4.58	3.02	487.8	-4.58	2.90	498.1	-4.58	2.80	506.0	-4.58	2.71	512.0
DEC 22	-4.46	3.09	451.2	-4.46	2.97	464.8	-4.46	2.86	475.5	-4.46	2.76	483.8	-4.46	2.68	490.1
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	270.984		.5156	271.095		.5158	270.477		.5146	269.315		.5124	267.751		.5094

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE LINE AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 42 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	41.7		7.7	41.0		15.1	39.9		22.0	38.4		28.3	36.8		33.9
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	7.01	1021.3	-7.54	6.48	1014.3	-7.54	5.95	1003.9	-7.54	5.46	990.8	-7.54	5.00	976.1
JUN 1 JUL 12	-7.42	6.89	1001.0	-7.42	6.36	994.6	-7.42	5.85	984.8	-7.42	5.36	972.5	-7.42	4.91	958.6
MAY 18 JUL 27	-7.23	6.70	965.7	-7.23	6.18	960.0	-7.23	5.67	951.3	-7.23	5.19	940.3	-7.23	4.75	927.8
MAY 3 AUG 10	-6.97	6.45	914.1	-6.97	5.93	909.4	-6.97	5.43	902.1	-6.97	4.97	892.9	-6.97	4.54	882.3
APR 19 AUG 25	-6.67	6.15	847.3	-6.67	5.64	843.8	-6.67	5.15	838.3	-6.67	4.70	831.2	-6.67	4.29	822.8
APR 4 SEP 9	-6.34	5.83	768.8	-6.34	5.32	766.5	-6.34	4.85	762.8	-6.34	4.41	758.0	-6.34	4.02	752.0
MAR 21 SEP 23	-6.00	5.49	681.2	-6.00	5.00	680.2	-6.00	4.53	678.4	-6.00	4.11	675.7	-6.00	3.74	672.2
MAR 7 OCT 8	-5.66	5.15	591.2	-5.66	4.67	591.3	-5.66	4.22	591.1	-5.66	3.81	590.5	-5.66	3.46	589.0
FEB 20 OCT 22	-5.33	4.83	505.1	-5.33	4.35	506.2	-5.33	3.92	507.4	-5.33	3.53	508.3	-5.33	3.19	508.7
FEB 7 NOV 5	-5.03	4.53	428.4	-5.03	4.06	430.2	-5.03	3.64	432.4	-5.03	3.26	434.6	-5.03	2.94	436.4
JAN 23 NOV 19	-4.77	4.27	367.1	-4.77	3.81	369.4	-4.77	3.40	372.3	-4.77	3.04	375.4	-4.77	2.72	378.1
JAN 10 DEC 3	-4.58	4.08	324.4	-4.58	3.63	327.0	-4.58	3.22	330.4	-4.58	2.87	334.0	-4.58	2.57	337.2
DEC 22	-4.46	3.97	299.8	-4.46	3.51	302.6	-4.46	3.12	306.2	-4.46	2.77	310.0	-4.46	2.47	313.5
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	247.032		.4700	246.441		.4689	245.455		.4670	244.082		.4644	242.359		.4611

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	35.0		38.9	33.2		43.3	31.5		47.1	29.8		50.4	28.2		53.4
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	4.59	960.3	-7.54	4.22	944.0	-7.54	3.89	927.8	-7.54	3.60	911.9	-7.54	3.34	896.4
JUN 1 JUL 12	-7.42	4.50	943.6	-7.42	4.14	928.2	-7.42	3.81	912.7	-7.42	3.53	897.5	-7.42	3.28	882.8
MAY 18 JUL 27	-7.23	4.35	914.2	-7.23	4.00	900.2	-7.23	3.69	886.0	-7.23	3.41	872.1	-7.23	3.17	858.4
MAY 3 AUG 10	-6.97	4.16	870.7	-6.97	3.82	858.6	-6.97	3.51	846.2	-6.97	3.25	834.0	-6.97	3.02	821.9
APR 19 AUG 25	-6.67	3.92	813.5	-6.67	3.60	803.6	-6.67	3.31	793.4	-6.67	3.06	783.2	-6.67	2.84	772.9
APR 4 SEP 9	-6.34	3.67	745.2	-6.34	3.36	737.7	-6.34	3.09	729.8	-6.34	2.85	721.7	-6.34	2.64	713.5
MAR 21 SEP 23	-6.00	3.41	667.8	-6.00	3.11	662.7	-6.00	2.86	657.1	-6.00	2.64	651.1	-6.00	2.44	644.9
MAR 7 OCT 8	-5.66	3.14	586.9	-5.66	2.87	584.0	-5.66	2.63	580.5	-5.66	2.42	576.5	-5.66	2.24	572.2
FEB 20 OCT 22	-5.33	2.89	508.4	-5.33	2.63	507.3	-5.33	2.41	505.6	-5.33	2.21	503.4	-5.33	2.04	500.7
FEB 7 NOV 5	-5.03	2.65	437.5	-5.03	2.41	437.8	-5.03	2.20	437.5	-5.03	2.02	436.6	-5.03	1.87	435.2
JAN 23 NOV 19	-4.77	2.46	380.1	-4.77	2.23	381.4	-4.77	2.03	382.1	-4.77	1.86	382.1	-4.77	1.72	381.6
JAN 10 DEC 3	-4.58	2.31	339.8	-4.58	2.09	341.8	-4.58	1.90	343.0	-4.58	1.75	343.6	-4.58	1.61	343.7
DEC 22	-4.46	2.22	316.4	-4.46	2.01	318.6	-4.46	1.83	320.2	-4.46	1.67	321.1	-4.46	1.54	321.5
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	240.336		.4573	238.081		.4530	235.669		.4484	233.173		.4436	230.631		.4388

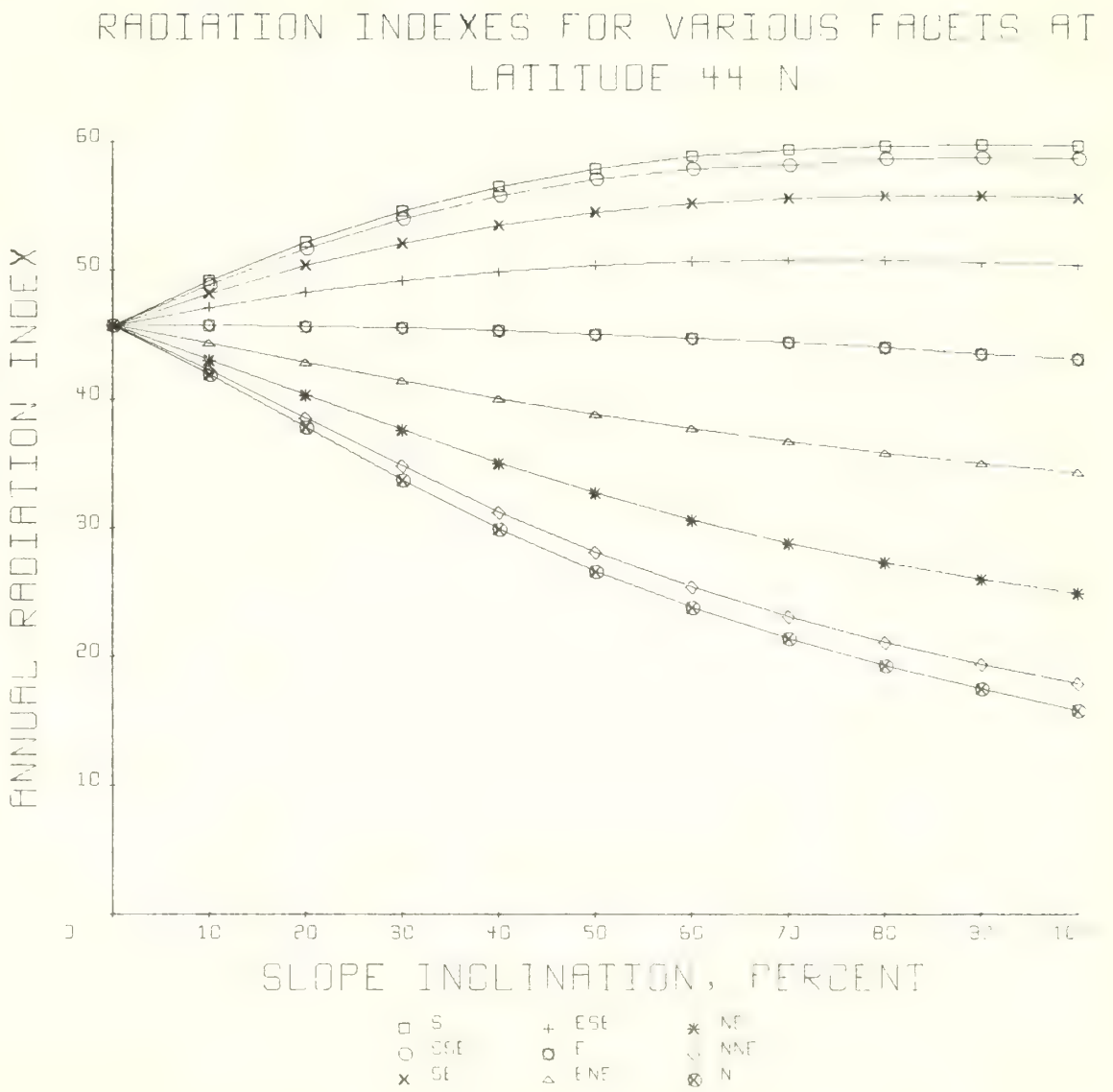
NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 44 N

		SR	SS	LY
JUN 22		-7.66	7.66	1024.0
JUN 1	JUL 12	-7.53	7.53	1001.8
MAY 18	JUL 27	-7.32	7.32	963.2
MAY 3	AUG 10	-7.04	7.04	907.2
APR 19	AUG 25	-6.72	6.72	835.4
APR 4	SEP 9	-6.36	6.36	751.9
MAR 21	SEP 23	-6.00	6.00	659.7
MAR 7	OCT 8	-5.64	5.64	565.8
FEB 20	OCT 22	-5.28	5.28	476.9
FEB 7	NOV 5	-4.96	4.96	398.5
JAN 23	NOV 19	-4.68	4.68	336.3
JAN 10	DEC 3	-4.47	4.47	293.4
DEC 22		-4.34	4.34	268.7

YEAR	R.I.
240.588	.4577



LATITUDE 44 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	49.7		0.0	55.3		0.0	60.7		0.0	65.8		0.0	70.6		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.66	1018.6	-7.66	7.66	1003.5	-7.66	7.66	980.0	-7.66	7.66	949.7	-7.66	7.66	914.6
JUN 1 JUL 12	-7.53	7.53	991.2	-7.53	7.53	971.3	-7.53	7.53	943.5	-7.53	7.53	909.4	-7.53	7.53	871.0
MAY 18 JUL 27	-7.32	7.32	944.2	-7.32	7.32	916.4	-7.32	7.32	881.5	-7.32	7.32	841.2	-7.32	7.32	797.5
MAY 3 AUG 10	-7.04	7.04	877.0	-7.04	7.04	838.9	-7.04	7.04	794.7	-7.04	7.04	746.3	-7.04	7.04	695.8
APR 19 AUG 25	-6.72	6.72	792.6	-6.72	6.72	742.9	-6.72	6.72	688.5	-6.72	6.72	631.3	-6.72	6.72	573.3
APR 4 SEP 9	-6.36	6.36	696.4	-6.36	6.36	635.4	-6.36	6.36	571.0	-6.36	6.36	505.3	-6.36	6.36	440.3
MAR 21 SEP 23	-6.00	6.00	593.0	-6.00	6.00	521.9	-6.00	6.00	448.8	-6.00	6.00	375.9	-6.00	6.00	305.1
MAR 7 OCT 8	-5.55	5.55	490.2	-5.45	5.45	411.7	-5.33	5.33	332.9	-5.15	5.15	256.2	-4.92	4.92	183.7
FEB 20 OCT 22	-5.12	5.12	395.4	-4.92	4.92	313.0	-4.66	4.66	232.7	-4.31	4.31	157.3	-3.79	3.79	89.7
FEB 7 NOV 5	-4.72	4.72	314.0	-4.42	4.42	230.9	-4.01	4.01	152.7	-3.44	3.44	83.2	-2.52	2.52	27.5
JAN 23 NOV 19	-4.37	4.37	251.1	-3.97	3.97	169.6	-3.42	3.42	96.0	-2.58	2.58	35.7	-.40	.40	.1
JAN 10 DEC 3	-4.11	4.11	208.7	-3.62	3.62	129.6	-2.94	2.94	61.2	-1.74	1.74	11.2	0.00	0.00	0.0
DEC 22	-3.94	3.94	184.8	-3.40	3.40	107.7	-2.61	2.61	43.3	-.96	.96	2.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	220.380		.4193	199.035		.3787	177.574		.3378	157.233		.2992	139.981		.2663

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	75.0		0.0	79.0		0.0	82.7		0.0	86.0		0.0	89.0		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.66	876.5	-7.66	7.66	837.1	-7.66	7.66	797.7	-7.66	7.66	759.2	-7.66	7.66	721.8
JUN 1 JUL 12	-7.53	7.53	830.2	-7.53	7.53	788.5	-7.53	7.53	747.2	-7.53	7.53	707.2	-7.53	7.53	668.5
MAY 18 JUL 27	-7.32	7.32	752.3	-7.32	7.32	706.9	-7.32	7.32	662.7	-7.32	7.32	620.3	-7.32	7.32	579.7
MAY 3 AUG 10	-7.04	7.04	644.9	-7.04	7.04	594.9	-7.04	7.04	546.9	-7.04	7.04	501.5	-7.04	7.04	458.5
APR 19 AUG 25	-6.72	6.72	516.3	-6.72	6.72	461.3	-6.72	6.72	409.4	-6.72	6.72	360.9	-6.72	6.72	315.5
APR 4 SEP 9	-6.36	6.36	377.6	-6.36	6.36	318.1	-6.36	6.36	262.7	-6.36	6.36	211.6	-6.36	6.36	164.2
MAR 21 SEP 23	-6.00	6.00	237.9	-6.00	6.00	175.0	-6.00	6.00	117.1	-6.00	6.00	64.3	-6.00	6.00	15.7
MAR 7 OCT 8	-4.56	4.56	117.2	-3.97	3.97	58.7	-2.66	2.66	12.7	0.00	0.00	0.0	0.00	0.00	0.0
FEB 20 OCT 22	-2.94	2.94	34.0	-.47	.47	.1	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
FEB 7 NOV 5	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	125.325		.2384	112.522		.2141	101.474		.1931	91.958		.1750	83.301		.1585

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 44 N
ASPECT S -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 38.3		ALPHA 0.0	THETA 32.7		ALPHA 0.0	THETA 27.3		ALPHA 0.0	THETA 22.2		ALPHA 0.0	THETA 17.4		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.34	7.34	1021.2	-7.08	7.08	1012.0	-6.86	6.86	996.5	-6.68	6.68	975.5	-6.52	6.52	950.3
JUN 1 JUL 12	-7.24	7.24	1004.2	-7.00	7.00	999.6	-6.80	6.80	988.4	-6.63	6.63	971.4	-6.49	6.49	949.7
MAY 18 JUL 27	-7.07	7.07	974.0	-6.87	6.87	977.4	-6.70	6.70	973.4	-6.55	6.55	963.0	-6.42	6.42	947.3
MAY 3 AUG 10	-6.85	6.85	929.3	-6.69	6.69	943.4	-6.55	6.55	949.5	-6.44	6.44	948.5	-6.33	6.33	941.0
APR 19 AUG 25	-6.58	6.58	870.4	-6.47	6.47	897.0	-6.38	6.38	914.9	-6.30	6.30	924.9	-6.23	6.23	927.9
APR 4 SEP 9	-6.30	6.30	800.0	-6.24	6.24	839.5	-6.19	6.19	870.1	-6.15	6.15	892.2	-6.12	6.12	906.5
MAR 21 SEP 23	-6.00	6.00	719.9	-6.00	6.00	771.9	-6.00	6.00	815.0	-6.00	6.00	849.1	-6.00	6.00	875.0
MAR 7 OCT 8	-5.64	5.64	636.0	-5.64	5.64	698.6	-5.64	5.64	752.5	-5.64	5.64	797.4	-5.64	5.64	833.7
FEB 20 OCT 22	-5.28	5.28	554.2	-5.28	5.28	624.6	-5.28	5.28	686.7	-5.28	5.28	739.9	-5.28	5.28	784.3
FEB 7 NOV 5	-4.96	4.96	480.1	-4.96	4.96	555.4	-4.96	4.96	622.8	-4.96	4.96	681.6	-4.96	4.96	731.7
JAN 23 NOV 19	-4.68	4.68	419.9	-4.68	4.68	497.7	-4.68	4.68	568.1	-4.68	4.68	630.2	-4.68	4.68	683.7
JAN 10 DEC 3	-4.47	4.47	377.5	-4.47	4.47	456.2	-4.47	4.47	527.9	-4.47	4.47	591.4	-4.47	4.47	646.6
DEC 22	-4.34	4.34	352.7	-4.34	4.34	431.6	-4.34	4.34	503.6	-4.34	4.34	567.7	-4.34	4.34	623.6
	YEAR 258.813		R.I. .4924	YEAR 274.472		R.I. .5222	YEAR 287.281		R.I. .5466	YEAR 297.247		R.I. .5655	YEAR 304.567		R.I. .5795

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 13.0		ALPHA 0.0	THETA 9.0		ALPHA 0.0	THETA 5.3		ALPHA 0.0	THETA 2.0		ALPHA 0.0	THETA -1.0		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.39	6.39	922.3	-6.26	6.26	892.7	-6.16	6.16	862.7	-6.06	6.06	833.0	-5.97	5.97	804.1
JUN 1 JUL 12	-6.36	6.36	924.6	-6.24	6.24	897.9	-6.14	6.14	870.3	-6.05	6.05	842.7	-5.97	5.97	815.5
MAY 18 JUL 27	-6.31	6.31	927.7	-6.21	6.21	905.6	-6.13	6.13	882.0	-6.05	6.05	857.9	-5.98	5.98	833.9
MAY 3 AUG 10	-6.25	6.25	929.0	-6.17	6.17	913.5	-6.10	6.10	895.8	-6.04	6.04	876.9	-5.98	5.98	857.4
APR 19 AUG 25	-6.17	6.17	925.2	-6.12	6.12	918.1	-6.07	6.07	907.9	-6.03	6.03	895.5	-5.99	5.99	881.8
APR 4 SEP 9	-6.09	6.09	914.2	-6.06	6.06	916.5	-6.04	6.04	914.8	-6.01	6.01	910.0	-5.99	5.99	903.0
MAR 21 SEP 23	-6.00	6.00	893.5	-6.00	6.00	905.8	-6.00	6.00	913.1	-6.00	6.00	916.5	-6.00	6.00	917.0
MAR 7 OCT 8	-5.64	5.64	862.1	-5.64	5.64	883.7	-5.64	5.64	899.5	-5.64	5.64	910.6	-5.64	5.64	918.1
FEB 20 OCT 22	-5.28	5.28	820.5	-5.28	5.28	849.5	-5.28	5.28	872.2	-5.28	5.28	889.6	-5.28	5.28	902.9
FEB 7 NOV 5	-4.96	4.96	773.5	-4.96	4.96	807.8	-4.96	4.96	835.5	-4.96	4.96	857.6	-4.96	4.96	875.2
JAN 23 NOV 19	-4.68	4.68	728.8	-4.68	4.68	766.5	-4.68	4.68	797.4	-4.68	4.68	822.6	-4.68	4.68	843.1
JAN 10 DEC 3	-4.47	4.47	693.6	-4.47	4.47	733.0	-4.47	4.47	765.8	-4.47	4.47	792.7	-4.47	4.47	814.9
DEC 22	-4.34	4.34	671.3	-4.34	4.34	711.6	-4.34	4.34	745.2	-4.34	4.34	772.9	-4.34	4.34	795.9
	YEAR		R.I. .5690	YEAR 312.607		R.I. .5948	YEAR 314.100		R.I. .5976	YEAR 314.395		R.I. .5982	YEAR 313.789		R.I. .5970

NOTE - FOR ASPECTS WITH W-E COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 44 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 49.2		ALPHA 3.3	THETA 54.2		ALPHA 7.4	THETA 58.9		ALPHA 12.3	THETA 63.1		ALPHA 18.3	THETA 66.7		ALPHA 25.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.66	1018.6	-7.66	7.66	1003.6	-7.66	7.66	980.0	-7.66	7.66	949.8	-7.66	7.66	914.7
JUN 1 JUL 12	-7.53	7.53	991.7	-7.53	7.53	972.2	-7.53	7.53	944.7	-7.53	7.53	910.9	-7.53	7.53	872.9
MAY 18 JUL 27	-7.32	7.32	945.3	-7.32	7.32	918.5	-7.32	7.32	884.6	-7.32	7.32	845.2	-7.32	7.32	802.4
MAY 3 AUG 10	-7.04	7.04	878.9	-7.04	7.03	842.7	-7.04	7.02	800.3	-7.04	7.00	753.7	-7.04	6.98	704.7
APR 19 AUG 25	-6.72	6.64	795.6	-6.72	6.54	749.0	-6.72	6.42	697.6	-6.72	6.27	643.5	-6.72	6.06	588.8
APR 4 SEP 9	-6.36	6.21	700.6	-6.36	6.03	644.1	-6.36	5.81	584.8	-6.36	5.53	524.7	-6.36	5.17	466.2
MAR 21 SEP 23	-6.00	5.78	598.3	-6.00	5.51	533.6	-6.00	5.18	468.2	-6.00	4.78	404.4	-6.00	4.29	344.7
MAR 7 OCT 8	-5.64	5.34	496.5	-5.64	4.98	425.9	-5.64	4.55	357.0	-5.64	4.03	292.2	-5.64	3.41	234.1
FEB 20 OCT 22	-5.28	4.92	402.3	-5.28	4.47	328.6	-5.28	3.94	258.8	-5.28	3.29	195.7	-5.28	2.51	141.8
FEB 7 NOV 5	-4.96	4.52	321.1	-4.96	3.99	246.6	-4.96	3.34	178.4	-4.96	2.56	119.2	-4.96	1.60	71.6
JAN 23 NOV 19	-4.62	4.18	258.2	-4.55	3.56	184.8	-4.45	2.81	119.7	-4.30	1.86	66.0	-4.07	.65	26.6
JAN 10 DEC 3	-4.36	3.92	215.7	-4.22	3.24	144.2	-4.02	2.38	82.8	-3.71	1.27	35.1	-3.07	-.35	5.2
DEC 22	-4.20	3.76	191.7	-4.02	3.03	121.8	-3.74	2.10	63.3	-3.29	.85	20.2	0.00	0.00	0.0
	YEAR 221.977		R.I. .4223	YEAR 202.457		R.I. .3852	YEAR 182.960		R.I. .3481	YEAR 164.402		R.I. .3128	YEAR 147.772		R.I. .2811

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 69.7		ALPHA 34.5	THETA 71.8		ALPHA 44.8	THETA 73.3		ALPHA 56.1	THETA 73.9		ALPHA 67.6	THETA 74.0		ALPHA 78.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.66	876.7	-7.66	7.66	837.3	-7.66	7.66	797.8	-7.66	7.66	759.4	-7.66	7.66	722.2
JUN 1 JUL 12	-7.53	7.53	832.4	-7.53	7.53	790.9	-7.53	7.53	749.9	-7.53	7.53	710.1	-7.53	7.53	671.8
MAY 18 JUL 27	-7.32	7.32	757.9	-7.32	7.32	713.2	-7.32	7.32	669.5	-7.32	7.32	627.6	-7.32	7.32	587.6
MAY 3 AUG 10	-7.04	6.95	655.1	-7.04	6.90	606.2	-7.04	6.79	559.2	-7.04	6.52	514.9	-7.04	5.84	473.4
APR 19 AUG 25	-6.72	5.79	535.2	-6.72	5.42	484.2	-6.72	4.92	437.1	-6.72	4.29	395.0	-6.72	3.58	358.3
APR 4 SEP 9	-6.36	4.73	411.1	-6.36	4.18	360.9	-6.36	3.54	316.8	-6.36	2.83	279.6	-6.36	2.10	249.0
MAR 21 SEP 23	-6.00	3.70	290.8	-6.00	3.01	244.3	-6.00	2.26	205.8	-6.00	1.49	175.3	-6.00	.76	151.7
MAR 7 OCT 8	-5.64	2.67	184.3	-5.64	1.85	143.9	-5.64	.98	113.0	-5.64	.16	90.6	-5.64	-.58	74.8
FEB 20 OCT 22	-5.28	1.61	98.5	-5.28	.61	66.5	-5.28	-.40	44.9	-5.28	-1.31	31.4	-5.28	-2.05	23.3
FEB 7 NOV 5	-4.96	.45	37.0	-4.96	-.87	15.4	-4.96	-2.27	4.7	-4.96	-3.54	1.1	-4.96	-4.31	.3
JAN 23 NOV 19	-3.56	-1.04	3.7	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 133.767		R.I. .2545	YEAR 121.752		R.I. .2316	YEAR 111.325		R.I. .2118	YEAR 102.329		R.I. .1947	YEAR 94.520		R.I. .1798

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 44 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 38.7		ALPHA 2.8	THETA 33.4		ALPHA 5.2	THETA 28.3		ALPHA 7.2	THETA 23.5		ALPHA 8.9	THETA 18.9		ALPHA 10.4
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.54	7.17	1021.6	-7.46	6.77	1013.6	-7.38	6.42	999.9	-7.32	6.13	981.2	-7.27	5.88	958.6
JUN 1 JUL 12	-7.44	7.07	1004.2	-7.37	6.68	1000.6	-7.32	6.36	991.1	-7.27	6.06	976.2	-7.22	5.83	957.0
MAY 18 JUL 27	-7.27	6.90	973.5	-7.24	6.55	977.3	-7.20	6.25	974.7	-7.18	5.99	966.2	-7.16	5.77	952.8
MAY 3 AUG 10	-7.04	6.67	928.0	-7.04	6.36	942.0	-7.04	6.10	948.9	-7.04	5.87	949.2	-7.04	5.67	943.9
APR 19 AUG 25	-6.72	6.41	868.2	-6.72	6.14	893.8	-6.72	5.92	911.8	-6.72	5.73	922.5	-6.72	5.56	926.9
APR 4 SEP 9	-6.36	6.12	796.7	-6.36	5.90	834.1	-6.36	5.72	863.5	-6.36	5.57	885.2	-6.36	5.43	899.6
MAR 21 SEP 23	-6.00	5.81	715.5	-6.00	5.66	763.9	-6.00	5.52	804.2	-6.00	5.41	836.2	-6.00	5.31	860.4
MAR 7 OCT 8	-5.64	5.51	630.6	-5.64	5.41	688.3	-5.64	5.32	737.9	-5.64	5.24	778.9	-5.64	5.18	811.9
FEB 20 OCT 22	-5.28	5.22	548.2	-5.28	5.17	612.9	-5.28	5.12	669.5	-5.28	5.09	717.8	-5.28	5.05	757.9
FEB 7 NOV 5	-4.96	4.95	473.7	-4.96	4.95	542.9	-4.96	4.95	604.5	-4.96	4.94	657.9	-4.96	4.94	703.2
JAN 23 NOV 19	-4.68	4.68	413.4	-4.68	4.68	485.0	-4.68	4.68	549.4	-4.68	4.68	606.0	-4.68	4.68	654.5
JAN 10 DEC 3	-4.47	4.47	371.0	-4.47	4.47	443.4	-4.47	4.47	509.1	-4.47	4.47	567.1	-4.47	4.47	617.3
DEC 22	-4.34	4.34	346.2	-4.34	4.34	418.8	-4.34	4.34	484.9	-4.34	4.34	543.5	-4.34	4.34	594.4
	YEAR 257.468		R.I. .4899	YEAR 272.030		R.I. .5176	YEAR 283.974		R.I. .5403	YEAR 293.279		R.I. .5580	YEAR 300.114		R.I. .5710

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 14.7		ALPHA 11.7	THETA 10.8		ALPHA 12.9	THETA 7.3		ALPHA 13.9	THETA 4.1		ALPHA 14.9	THETA 1.2		ALPHA 15.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.22	5.65	933.4	-7.18	5.46	906.6	-7.14	5.28	879.2	-7.11	5.13	852.1	-7.08	4.99	825.5
JUN 1 JUL 12	-7.19	5.62	934.7	-7.16	5.43	910.6	-7.13	5.27	885.5	-7.10	5.12	860.4	-7.08	4.99	835.6
MAY 18 JUL 27	-7.14	5.57	935.7	-7.12	5.40	916.1	-7.10	5.24	895.1	-7.09	5.11	873.5	-7.08	4.98	851.8
MAY 3 AUG 10	-7.04	5.50	934.1	-7.04	5.34	921.0	-7.04	5.21	905.8	-7.04	5.09	889.2	-7.04	4.98	872.0
APR 19 AUG 25	-6.72	5.41	925.8	-6.72	5.28	920.6	-6.72	5.16	912.4	-6.72	5.06	902.0	-6.72	4.97	890.3
APR 4 SEP 9	-6.36	5.32	907.9	-6.36	5.21	911.1	-6.36	5.12	910.4	-6.36	5.04	906.8	-6.36	4.96	901.0
MAR 21 SEP 23	-6.00	5.22	877.8	-6.00	5.14	889.4	-6.00	5.07	896.2	-6.00	5.01	899.4	-6.00	4.95	899.8
MAR 7 OCT 8	-5.64	5.12	837.5	-5.64	5.07	856.7	-5.64	5.02	870.5	-5.64	4.98	880.0	-5.64	4.95	886.2
FEB 20 OCT 22	-5.28	5.02	790.2	-5.28	5.00	815.8	-5.28	4.98	835.6	-5.28	4.96	850.6	-5.28	4.94	861.7
FEB 7 NOV 5	-4.96	4.94	740.6	-4.96	4.94	771.1	-4.96	4.93	795.6	-4.96	4.93	814.9	-4.96	4.93	830.0
JAN 23 NOV 19	-4.68	4.68	695.3	-4.68	4.68	729.1	-4.68	4.68	756.7	-4.68	4.68	779.0	-4.68	4.68	797.1
JAN 10 DEC 3	-4.47	4.47	659.9	-4.47	4.47	695.5	-4.47	4.47	724.9	-4.47	4.47	749.0	-4.47	4.47	768.6
DEC 22	-4.34	4.34	637.8	-4.34	4.34	674.2	-4.34	4.34	704.4	-4.34	4.34	729.3	-4.34	4.34	749.8
	YEAR 304.763		R.I. .5798	YEAR 307.594		R.I. .5852	YEAR 308.959		R.I. .5878	YEAR 309.197		R.I. .5883	YEAR 308.587		R.I. .5871

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 44 N
ASPECT NE - NW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	47.9		6.0	51.3		12.8	54.2		20.3	56.5		28.4	58.1		36.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.52	1018.9	-7.66	7.34	1004.4	-7.66	7.12	982.0	-7.66	6.84	953.6	-7.66	6.50	921.2
JUN 1 JUL 12	-7.53	7.36	993.1	-7.53	7.16	975.5	-7.53	6.91	950.6	-7.53	6.61	920.3	-7.53	6.24	886.8
MAY 18 JUL 27	-7.32	7.12	948.7	-7.32	6.88	926.2	-7.32	6.59	897.3	-7.32	6.24	864.1	-7.32	5.84	828.8
MAY 3 AUG 10	-7.04	6.80	885.1	-7.04	6.50	856.2	-7.04	6.16	822.4	-7.04	5.77	785.8	-7.04	5.32	748.5
APR 19 AUG 25	-6.72	6.42	804.8	-6.72	6.07	769.0	-6.72	5.68	730.1	-6.72	5.24	690.3	-6.72	4.75	651.4
APR 4 SEP 9	-6.36	6.02	712.8	-6.36	5.62	670.5	-6.36	5.17	627.2	-6.36	4.68	585.0	-6.36	4.16	545.4
MAR 21 SEP 23	-6.00	5.60	613.2	-6.00	5.14	565.6	-6.00	4.64	519.2	-6.00	4.11	475.7	-6.00	3.55	436.7
MAR 7 OCT 8	-5.64	5.18	513.6	-5.64	4.67	462.3	-5.64	4.12	414.2	-5.64	3.53	371.1	-5.64	2.94	333.8
FEB 20 OCT 22	-5.28	4.78	420.9	-5.28	4.21	367.7	-5.28	3.61	319.7	-5.28	2.98	278.2	-5.28	2.35	243.8
FEB 7 NOV 5	-4.96	4.40	340.5	-4.96	3.78	287.1	-4.96	3.12	240.5	-4.96	2.44	201.7	-4.96	1.78	170.7
JAN 23 NOV 19	-4.68	4.08	277.8	-4.68	3.41	225.4	-4.68	2.70	180.9	-4.68	1.97	145.1	-4.68	1.27	117.8
JAN 10 DEC 3	-4.47	3.83	235.2	-4.47	3.13	184.0	-4.47	2.37	141.6	-4.47	1.60	108.6	-4.47	.86	84.2
DEC 22	-4.34	3.68	211.0	-4.34	2.95	160.8	-4.34	2.17	119.9	-4.34	1.37	88.7	-4.34	.60	66.3
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	226.458		.4309	211.899		.4032	197.612		.3760	184.160		.3504	171.946		.3271

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	59.0		45.0	59.4		52.8	59.3		60.0	58.9		66.5	58.3		72.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	6.10	887.2	-7.66	5.63	853.1	-7.66	5.14	820.6	-7.66	4.65	790.6	-7.66	4.18	763.2
JUN 1 JUL 12	-7.53	5.82	852.1	-7.53	5.35	817.9	-7.53	4.86	785.7	-7.53	4.37	756.2	-7.53	3.91	729.4
MAY 18 JUL 27	-7.32	5.39	793.2	-7.32	4.90	759.1	-7.32	4.42	727.5	-7.32	3.94	698.9	-7.32	3.50	673.3
MAY 3 AUG 10	-7.04	4.85	712.3	-7.04	4.35	678.5	-7.04	3.87	647.9	-7.04	3.41	620.8	-7.04	2.98	596.9
APR 19 AUG 25	-6.72	4.25	615.1	-6.72	3.75	582.3	-6.72	3.26	553.4	-6.72	2.81	528.3	-6.72	2.41	506.5
APR 4 SEP 9	-6.36	3.63	509.9	-6.36	3.12	478.8	-6.36	2.64	452.1	-6.36	2.20	429.6	-6.36	1.80	410.4
MAR 21 SEP 23	-6.00	3.00	403.0	-6.00	2.48	374.4	-6.00	2.00	350.7	-6.00	1.57	331.1	-6.00	1.19	314.9
MAR 7 OCT 8	-5.64	2.37	302.8	-5.64	1.84	277.5	-5.64	1.36	257.2	-5.64	.94	240.9	-5.64	.58	227.7
FEB 20 OCT 22	-5.28	1.75	216.2	-5.28	1.21	194.6	-5.28	.73	177.9	-5.28	.32	164.9	-5.28	-.02	154.7
FEB 7 NOV 5	-4.96	1.16	147.0	-4.96	.60	129.2	-4.96	.13	116.0	-4.96	-.27	106.2	-4.96	-.60	98.7
JAN 23 NOV 19	-4.68	.62	97.7	-4.68	.05	83.4	-4.68	-.42	73.2	-4.68	-.81	65.9	-4.68	-1.12	60.6
JAN 10 DEC 3	-4.47	.19	67.1	-4.47	-.39	55.4	-4.47	-.86	47.5	-4.47	-1.23	42.0	-4.47	-1.53	38.2
DEC 22	-4.34	-.09	51.1	-4.34	-.68	41.0	-4.34	-1.15	34.4	-4.34	-1.51	30.1	-4.34	-1.79	27.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	161.165		.3066	151.819		.2888	143.828		.2736	137.040		.2607	131.234		.2497

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 44 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 39.8		ALPHA 5.3	THETA 35.5		ALPHA 9.8	THETA 31.3		ALPHA 13.8	THETA 27.1		ALPHA 17.2	THETA 23.2		ALPHA 20.1
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.07	1022.5	-7.66	6.55	1017.1	-7.66	6.10	1007.7	-7.66	5.71	994.4	-7.66	5.37	978.0
JUN 1 JUL 12	-7.53	6.96	1004.0	-7.53	6.46	1002.2	-7.53	6.03	996.1	-7.53	5.65	985.9	-7.53	5.32	972.2
MAY 18 JUL 27	-7.32	6.78	971.5	-7.32	6.31	975.5	-7.32	5.90	974.9	-7.32	5.55	969.8	-7.32	5.23	960.8
MAY 3 AUG 10	-7.04	6.55	923.6	-7.04	6.11	935.5	-7.04	5.73	942.2	-7.04	5.40	944.0	-7.04	5.12	941.2
APR 19 AUG 25	-6.72	6.27	861.0	-6.72	5.87	881.7	-6.72	5.53	896.9	-6.72	5.23	906.6	-6.72	4.97	911.1
APR 4 SEP 9	-6.36	5.96	786.6	-6.36	5.61	816.3	-6.36	5.31	840.1	-6.36	5.05	857.9	-6.36	4.82	870.0
MAR 21 SEP 23	-6.00	5.65	702.8	-6.00	5.35	740.7	-6.00	5.08	772.6	-6.00	4.86	798.0	-6.00	4.66	817.3
MAR 7 OCT 8	-5.64	5.33	615.7	-5.64	5.08	660.5	-5.64	4.85	699.0	-5.64	4.66	731.0	-5.64	4.50	756.5
FEB 20 OCT 22	-5.28	5.03	531.7	-5.28	4.82	581.4	-5.28	4.63	625.0	-5.28	4.48	661.9	-5.28	4.34	692.3
FEB 7 NOV 5	-4.96	4.75	456.1	-4.96	4.58	509.0	-4.96	4.43	555.8	-4.96	4.31	596.2	-4.96	4.20	629.9
JAN 23 NOV 19	-4.68	4.51	395.2	-4.68	4.38	449.6	-4.68	4.26	498.3	-4.68	4.17	540.6	-4.68	4.08	576.5
JAN 10 DEC 3	-4.47	4.34	352.6	-4.47	4.23	407.6	-4.47	4.14	457.0	-4.47	4.06	500.2	-4.47	3.99	537.2
DEC 22	-4.34	4.23	327.9	-4.34	4.14	382.9	-4.34	4.06	432.5	-4.34	4.00	476.1	-4.34	3.94	513.5
	YEAR 253.592		R.I. .4825	YEAR 264.927		R.I. .5040	YEAR 274.274		R.I. .5218	YEAR 281.555		R.I. .5357	YEAR 286.865		R.I. .5458

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 19.5		ALPHA 22.7	THETA 16.1		ALPHA 25.0	THETA 13.0		ALPHA 27.0	THETA 10.1		ALPHA 28.7	THETA 7.6		ALPHA 30.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	5.08	959.3	-7.66	4.82	939.0	-7.66	4.59	918.2	-7.66	4.38	897.2	-7.66	4.20	876.5
JUN 1 JUL 12	-7.53	5.03	956.0	-7.53	4.78	938.0	-7.53	4.56	919.1	-7.53	4.36	899.9	-7.53	4.19	880.7
MAY 18 JUL 27	-7.32	4.96	948.8	-7.32	4.72	934.5	-7.32	4.51	918.8	-7.32	4.33	902.4	-7.32	4.16	885.7
MAY 3 AUG 10	-7.04	4.86	934.8	-7.04	4.64	925.6	-7.04	4.45	914.4	-7.04	4.28	901.9	-7.04	4.12	888.7
APR 19 AUG 25	-6.72	4.75	911.3	-6.72	4.55	908.0	-6.72	4.37	902.1	-6.72	4.22	894.3	-6.72	4.08	885.2
APR 4 SEP 9	-6.36	4.62	877.1	-6.36	4.44	880.0	-6.36	4.29	879.7	-6.36	4.15	876.8	-6.36	4.03	872.2
MAR 21 SEP 23	-6.00	4.49	831.0	-6.00	4.34	840.0	-6.00	4.20	845.1	-6.00	4.09	847.2	-6.00	3.98	847.1
MAR 7 OCT 8	-5.64	4.35	776.0	-5.64	4.23	790.4	-5.64	4.12	800.6	-5.64	4.02	807.2	-5.64	3.93	811.2
FEB 20 OCT 22	-5.28	4.23	716.5	-5.28	4.12	735.4	-5.28	4.03	749.6	-5.28	3.95	760.0	-5.28	3.88	767.5
FEB 7 NOV 5	-4.96	4.11	657.5	-4.96	4.03	679.7	-4.96	3.96	697.0	-4.96	3.89	710.3	-4.96	3.84	720.5
JAN 23 NOV 19	-4.68	4.01	606.2	-4.68	3.95	630.5	-4.68	3.89	650.0	-4.68	3.85	665.3	-4.68	3.80	677.4
JAN 10 DEC 3	-4.47	3.94	568.1	-4.47	3.89	593.6	-4.47	3.85	614.3	-4.47	3.81	630.9	-4.47	3.78	644.2
DEC 22	-4.34	3.90	545.0	-4.34	3.85	571.1	-4.34	3.82	592.4	-4.34	3.79	609.6	-4.34	3.76	623.5
	YEAR 290.411		R.I. .5525	YEAR 292.478		R.I. .5565	YEAR 293.351		R.I. .5581	YEAR 293.304		R.I. .5580	YEAR 292.566		R.I. .5566

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 44 N
ASPECT ENE - WNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	45.9	7.6		47.3	15.5		48.1	23.4		48.3	31.1		48.1	38.2	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.27	1020.0	-7.66	6.84	1009.2	-7.66	6.37	993.0	-7.66	5.88	973.2	-7.66	5.38	951.6
JUN 1 JUL 12	-7.53	7.14	996.0	-7.53	6.70	983.9	-7.53	6.22	966.9	-7.53	5.73	946.7	-7.53	5.23	925.1
MAY 18 JUL 27	-7.32	6.91	954.5	-7.32	6.46	940.2	-7.32	5.97	922.0	-7.32	5.48	901.3	-7.32	4.99	879.7
MAY 3 AUG 10	-7.04	6.61	894.7	-7.04	6.14	877.7	-7.04	5.65	857.9	-7.04	5.15	836.7	-7.04	4.66	815.3
APR 19 AUG 25	-6.72	6.26	818.6	-6.72	5.77	798.8	-6.72	5.27	777.4	-6.72	4.76	755.8	-6.72	4.28	734.8
APR 4 SEP 9	-6.36	5.88	730.8	-6.36	5.38	708.3	-6.36	4.86	685.8	-6.36	4.35	664.1	-6.36	3.87	643.9
MAR 21 SEP 23	-6.00	5.49	634.9	-6.00	4.97	610.4	-6.00	4.44	587.1	-6.00	3.93	565.7	-6.00	3.45	546.7
MAR 7 OCT 8	-5.64	5.10	538.2	-5.64	4.56	512.2	-5.64	4.02	488.8	-5.64	3.50	468.3	-5.64	3.03	450.8
FEB 20 OCT 22	-5.28	4.73	447.4	-5.28	4.16	420.9	-5.28	3.61	398.0	-5.28	3.09	378.7	-5.28	2.62	362.8
FEB 7 NOV 5	-4.96	4.38	368.0	-4.96	3.79	341.6	-4.96	3.23	319.6	-4.96	2.71	301.8	-4.96	2.24	287.6
JAN 23 NOV 19	-4.68	4.08	305.7	-4.68	3.47	279.8	-4.68	2.90	258.9	-4.68	2.38	242.5	-4.68	1.92	229.8
JAN 10 DEC 3	-4.47	3.85	262.9	-4.47	3.24	237.7	-4.47	2.66	217.9	-4.47	2.13	202.6	-4.47	1.67	191.1
DEC 22	-4.34	3.71	238.5	-4.34	3.09	213.8	-4.34	2.50	194.6	-4.34	1.98	180.1	-4.34	1.52	169.3
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	232.992	.4433		225.272	.4286		217.772	.4143		210.716	.4009		204.240	.3886	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	47.5	44.7		46.6	50.5		45.6	55.6		44.5	60.0		43.3	63.9	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	4.91	929.6	-7.66	4.46	907.9	-7.66	4.05	887.3	-7.66	3.68	868.0	-7.66	3.36	850.0
JUN 1 JUL 12	-7.53	4.76	903.3	-7.53	4.32	882.0	-7.53	3.92	861.9	-7.53	3.56	843.1	-7.53	3.23	825.6
MAY 18 JUL 27	-7.32	4.52	858.3	-7.32	4.09	837.7	-7.32	3.69	818.4	-7.32	3.34	800.5	-7.32	3.03	783.9
MAY 3 AUG 10	-7.04	4.20	794.6	-7.04	3.78	775.0	-7.04	3.40	756.8	-7.04	3.06	740.2	-7.04	2.76	724.9
APR 19 AUG 25	-6.72	3.83	715.1	-6.72	3.42	696.9	-6.72	3.05	680.3	-6.72	2.73	665.2	-6.72	2.44	651.4
APR 4 SEP 9	-6.36	3.43	625.5	-6.36	3.03	608.9	-6.36	2.68	594.0	-6.36	2.37	580.7	-6.36	2.10	568.7
MAR 21 SEP 23	-6.00	3.02	529.9	-6.00	2.63	515.2	-6.00	2.29	502.3	-6.00	2.00	490.9	-6.00	1.74	480.8
MAR 7 OCT 8	-5.64	2.61	435.8	-5.64	2.23	423.0	-5.64	1.91	412.1	-5.64	1.63	402.7	-5.64	1.39	394.4
FEB 20 OCT 22	-5.28	2.21	349.7	-5.28	1.85	338.9	-5.28	1.54	329.8	-5.28	1.27	322.2	-5.28	1.04	315.5
FEB 7 NOV 5	-4.96	1.84	276.3	-4.96	1.49	267.2	-4.96	1.19	259.8	-4.96	.94	253.7	-4.96	.73	248.5
JAN 23 NOV 19	-4.68	1.52	220.1	-4.68	1.18	212.4	-4.68	.90	206.3	-4.68	.66	201.4	-4.68	.46	197.3
JAN 10 DEC 3	-4.47	1.28	182.4	-4.47	.95	175.8	-4.47	.67	170.6	-4.47	.45	166.5	-4.47	.25	163.0
DEC 22	-4.34	1.13	161.3	-4.34	.81	155.2	-4.34	.54	150.6	-4.34	.32	146.9	-4.34	.13	143.9
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	198.383	.3774		193.121	.3674		188.412	.3585		184.199	.3505		180.389	.3432	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 44 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 41.6		ALPHA 7.1	THETA 38.8		ALPHA 13.5	THETA 35.9		ALPHA 19.1	THETA 32.9		ALPHA 24.1	THETA 29.9		ALPHA 28.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.04	1022.5	-7.66	6.47	1018.0	-7.66	5.95	1010.4	-7.66	5.48	1000.0	-7.66	5.07	987.4
JUN 1 JUL 12	-7.53	6.93	1002.4	-7.53	6.37	1000.0	-7.53	5.86	994.5	-7.53	5.40	986.1	-7.53	5.00	975.4
MAY 18 JUL 27	-7.32	6.74	967.3	-7.32	6.20	968.3	-7.32	5.71	966.3	-7.32	5.27	961.2	-7.32	4.88	953.5
MAY 3 AUG 10	-7.04	6.48	915.9	-7.04	5.97	921.6	-7.04	5.50	924.1	-7.04	5.08	923.5	-7.04	4.72	919.3
APR 19 AUG 25	-6.72	6.19	849.2	-6.72	5.70	860.3	-6.72	5.26	868.0	-6.72	4.87	872.4	-6.72	4.53	873.5
APR 4 SEP 9	-6.36	5.86	770.8	-6.36	5.41	787.2	-6.36	5.00	800.2	-6.36	4.64	809.7	-6.36	4.32	815.6
MAR 21 SEP 23	-6.00	5.53	683.3	-6.00	5.10	704.5	-6.00	4.72	722.5	-6.00	4.39	736.7	-6.00	4.10	747.1
MAR 7 OCT 8	-5.64	5.19	593.2	-5.64	4.80	618.4	-5.64	4.45	640.4	-5.64	4.15	658.6	-5.64	3.89	672.9
FEB 20 OCT 22	-5.28	4.87	507.0	-5.28	4.51	535.1	-5.28	4.19	560.0	-5.28	3.92	581.1	-5.28	3.68	598.4
FEB 7 NOV 5	-4.96	4.57	430.1	-4.96	4.24	459.9	-4.96	3.95	486.6	-4.96	3.70	509.7	-4.96	3.49	528.9
JAN 23 NOV 19	-4.68	4.32	368.7	-4.68	4.01	399.2	-4.68	3.74	426.9	-4.68	3.52	451.0	-4.68	3.33	471.3
JAN 10 DEC 3	-4.47	4.13	325.9	-4.47	3.84	356.7	-4.47	3.59	384.6	-4.47	3.39	409.1	-4.47	3.21	430.0
DEC 22	-4.34	4.02	301.2	-4.34	3.74	331.9	-4.34	3.50	359.9	-4.34	3.30	384.5	-4.34	3.14	405.6
	YEAR 247.661		R.I. .4712	YEAR 253.852		R.I. .4830	YEAR 258.912		R.I. .4926	YEAR 262.734		R.I. .4999	YEAR 265.337		R.I. .5048

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 27.0		ALPHA 32.2	THETA 24.3		ALPHA 35.5	THETA 21.7		ALPHA 38.4	THETA 19.4		ALPHA 40.9	THETA 17.3		ALPHA 43.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	4.70	973.0	-7.66	4.38	957.5	-7.66	4.10	941.4	-7.66	3.86	925.2	-7.66	3.64	909.1
JUN 1 JUL 12	-7.53	4.64	962.7	-7.53	4.33	948.7	-7.53	4.06	934.0	-7.53	3.82	919.0	-7.53	3.60	903.9
MAY 18 JUL 27	-7.32	4.54	943.6	-7.32	4.24	932.1	-7.32	3.97	919.7	-7.32	3.74	906.7	-7.32	3.54	893.4
MAY 3 AUG 10	-7.04	4.40	913.7	-7.04	4.11	905.7	-7.04	3.86	896.2	-7.04	3.65	886.0	-7.04	3.45	875.1
APR 19 AUG 25	-6.72	4.23	871.7	-6.72	3.96	867.6	-6.72	3.73	861.8	-6.72	3.53	854.7	-6.72	3.35	846.8
APR 4 SEP 9	-6.36	4.04	818.4	-6.36	3.80	818.4	-6.36	3.59	816.3	-6.36	3.40	812.6	-6.36	3.24	807.7
MAR 21 SEP 23	-6.00	3.85	754.1	-6.00	3.63	758.1	-6.00	3.44	759.6	-6.00	3.27	759.2	-6.00	3.12	757.4
MAR 7 OCT 8	-5.64	3.66	683.5	-5.64	3.46	691.0	-5.64	3.29	695.7	-5.64	3.14	698.3	-5.64	3.01	699.1
FEB 20 OCT 22	-5.28	3.47	611.9	-5.28	3.30	622.0	-5.28	3.14	629.3	-5.28	3.01	634.3	-5.28	2.89	637.4
FEB 7 NOV 5	-4.96	3.31	544.4	-4.96	3.15	556.5	-4.96	3.01	565.7	-4.96	2.90	572.5	-4.96	2.79	577.3
JAN 23 NOV 19	-4.68	3.16	487.9	-4.68	3.02	501.3	-4.68	2.90	511.7	-4.68	2.80	519.6	-4.68	2.71	525.6
JAN 10 DEC 3	-4.47	3.06	447.2	-4.47	2.93	461.2	-4.47	2.82	472.3	-4.47	2.73	480.9	-4.47	2.64	487.6
DEC 22	-4.34	3.00	423.0	-4.34	2.88	437.3	-4.34	2.77	448.7	-4.34	2.68	457.7	-4.34	2.61	464.7
	YEAR 266.827		R.I. .5077	YEAR 267.373		R.I. .5087	YEAR 267.158		R.I. .5083	YEAR 266.363		R.I. .5068	YEAR 265.135		R.I. .5044

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 44 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 43.7		ALPHA 7.9	THETA 42.9		ALPHA 15.5	THETA 41.7		ALPHA 22.6	THETA 40.2		ALPHA 29.1	THETA 38.4		ALPHA 34.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.11	1021.6	-7.66	6.55	1014.9	-7.66	6.01	1004.8	-7.66	5.50	992.4	-7.66	5.02	978.3
JUN 1 JUL 12	-7.53	6.98	999.5	-7.53	6.43	993.3	-7.53	5.90	984.0	-7.53	5.39	972.4	-7.53	4.92	959.2
MAY 18 JUL 27	-7.32	6.78	961.2	-7.32	6.23	955.8	-7.32	5.71	947.6	-7.32	5.21	937.4	-7.32	4.76	925.7
MAY 3 AUG 10	-7.04	6.50	905.7	-7.04	5.97	901.3	-7.04	5.45	894.7	-7.04	4.97	886.4	-7.04	4.53	876.7
APR 19 AUG 25	-6.72	6.18	834.3	-6.72	5.65	831.3	-6.72	5.15	826.5	-6.72	4.69	820.4	-6.72	4.27	813.1
APR 4 SEP 9	-6.36	5.83	751.3	-6.36	5.31	749.5	-6.36	4.83	746.8	-6.36	4.38	742.9	-6.36	3.98	738.2
MAR 21 SEP 23	-6.00	5.47	659.6	-6.00	4.96	659.2	-6.00	4.49	658.3	-6.00	4.06	656.7	-6.00	3.68	654.3
MAR 7 OCT 8	-5.64	5.11	566.1	-5.64	4.61	566.9	-5.64	4.15	567.7	-5.64	3.74	568.1	-5.64	3.38	567.9
FEB 20 OCT 22	-5.28	4.76	477.6	-5.28	4.27	479.3	-5.28	3.83	481.4	-5.28	3.44	483.4	-5.28	3.09	485.0
FEB 7 NOV 5	-4.96	4.44	399.4	-4.96	3.96	401.8	-4.96	3.53	404.9	-4.96	3.15	408.1	-4.96	2.83	410.9
JAN 23 NOV 19	-4.68	4.16	337.4	-4.68	3.69	340.3	-4.68	3.28	344.0	-4.68	2.91	348.0	-4.68	2.60	351.6
JAN 10 DEC 3	-4.47	3.96	294.6	-4.47	3.49	297.7	-4.47	3.09	301.8	-4.47	2.73	306.2	-4.47	2.44	310.3
DEC 22	-4.34	3.83	270.0	-4.34	3.37	273.2	-4.34	2.97	277.5	-4.34	2.63	282.1	-4.34	2.34	286.4
	YEAR 240.451		R.I. .4575	YEAR 240.032		R.I. .4567	YEAR 239.310		R.I. .4553	YEAR 238.263		R.I. .4533	YEAR 236.899		R.I. .4507

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 36.6		ALPHA 39.8	THETA 34.7		ALPHA 44.2	THETA 32.8		ALPHA 48.0	THETA 31.1		ALPHA 51.4	THETA 29.4		ALPHA 54.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	4.60	963.2	-7.66	4.22	947.7	-7.66	3.88	932.2	-7.66	3.59	917.0	-7.66	3.33	902.2
JUN 1 JUL 12	-7.53	4.50	945.0	-7.53	4.13	930.4	-7.53	3.80	915.8	-7.53	3.51	901.3	-7.53	3.26	887.2
MAY 18 JUL 27	-7.32	4.35	913.1	-7.32	3.99	900.0	-7.32	3.67	886.7	-7.32	3.39	873.5	-7.32	3.14	860.6
MAY 3 AUG 10	-7.04	4.14	866.2	-7.04	3.79	855.0	-7.04	3.49	843.6	-7.04	3.22	832.2	-7.04	2.99	821.0
APR 19 AUG 25	-6.72	3.89	805.0	-6.72	3.56	796.2	-6.72	3.27	787.0	-6.72	3.02	777.7	-6.72	2.80	768.4
APR 4 SEP 9	-6.36	3.62	732.5	-6.36	3.31	726.2	-6.36	3.04	719.4	-6.36	2.80	712.3	-6.36	2.59	705.0
MAR 21 SEP 23	-6.00	3.34	651.2	-6.00	3.05	647.3	-6.00	2.80	642.8	-6.00	2.58	637.9	-6.00	2.38	632.7
MAR 7 OCT 8	-5.64	3.06	566.9	-5.64	2.79	565.2	-5.64	2.55	562.8	-5.64	2.35	559.9	-5.64	2.17	556.5
FEB 20 OCT 22	-5.28	2.80	485.8	-5.28	2.54	485.8	-5.28	2.32	485.2	-5.28	2.13	483.9	-5.28	1.97	482.1
FEB 7 NOV 5	-4.96	2.55	413.0	-4.96	2.31	414.4	-4.96	2.11	415.1	-4.96	1.93	415.0	-4.96	1.78	414.5
JAN 23 NOV 19	-4.68	2.34	354.6	-4.68	2.11	356.9	-4.68	1.92	358.4	-4.68	1.76	359.2	-4.68	1.62	359.5
JAN 10 DEC 3	-4.47	2.18	313.8	-4.47	1.97	316.5	-4.47	1.79	318.5	-4.47	1.64	319.9	-4.47	1.51	320.7
DEC 22	-4.34	2.09	290.1	-4.34	1.88	293.1	-4.34	1.71	295.4	-4.34	1.56	297.0	-4.34	1.44	298.0
	YEAR 235.245		R.I. .4476	YEAR 233.351		R.I. .4440	YEAR 231.282		R.I. .4400	YEAR 229.104		R.I. .4359	YEAR 226.855		R.I. .4316

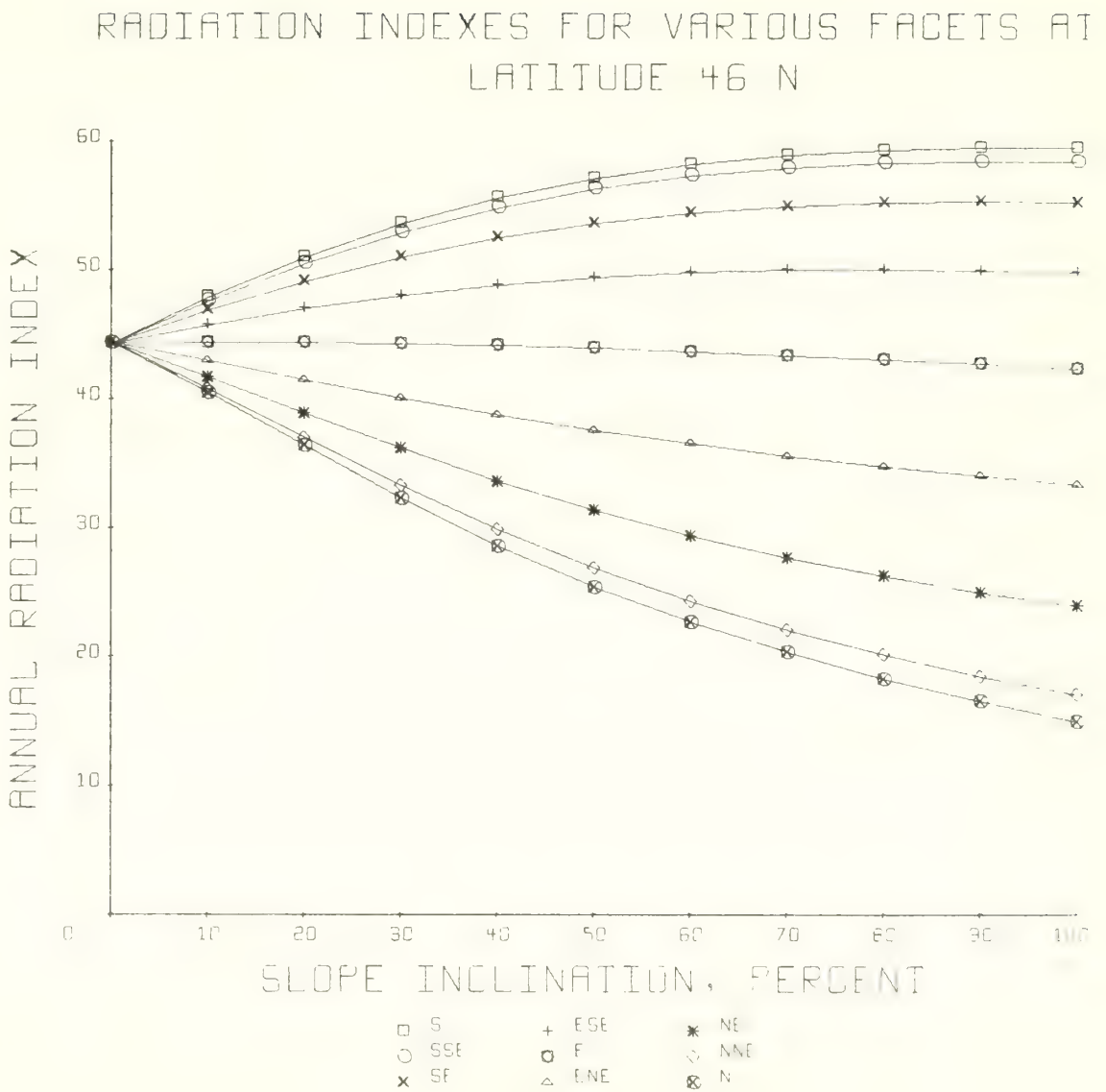
NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 46 N

		SR	SS	LY
JUN 22		-7.78	7.78	1023.6
JUN 1	JUL 12	-7.65	7.65	999.5
MAY 18	JUL 27	-7.42	7.42	957.8
MAY 3	AUG 10	-7.12	7.12	897.6
APR 19	AUG 25	-6.77	6.77	821.4
APR 4	SEP 9	-6.39	6.39	733.3
MAR 21	SEP 23	-6.00	6.00	637.1
MAR 7	OCT 8	-5.61	5.61	539.9
FEB 20	OCT 22	-5.23	5.23	448.8
FEB 7	NOV 5	-4.88	4.88	369.1
JAN 23	NOV 19	-4.58	4.58	306.4
JAN 10	DEC 3	-4.35	4.35	263.5
DEC 22		-4.22	4.22	239.0

YEAR	R.I.
233.753	.4447



LATITUDE 46 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 51.7		ALPHA 0.0	THETA 57.3		ALPHA 0.0	THETA 62.7		ALPHA 0.0	THETA 67.8		ALPHA 0.0	THETA 72.6		ALPHA 0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.78	1016.3	-7.78	7.78	999.4	-7.78	7.78	974.1	-7.78	7.78	942.3	-7.78	7.78	905.8
JUN 1 JUL 12	-7.65	7.65	986.9	-7.65	7.65	965.0	-7.65	7.65	935.4	-7.65	7.65	899.6	-7.65	7.65	859.8
MAY 18 JUL 27	-7.42	7.42	936.5	-7.42	7.42	906.7	-7.42	7.42	869.8	-7.42	7.42	827.8	-7.42	7.42	782.6
MAY 3 AUG 10	-7.12	7.12	865.1	-7.12	7.12	824.8	-7.12	7.12	778.6	-7.12	7.12	728.4	-7.12	7.12	676.4
APR 19 AUG 25	-6.77	6.77	776.1	-6.77	6.77	724.1	-6.77	6.77	667.7	-6.77	6.77	608.8	-6.77	6.77	549.3
APR 4 SEP 9	-6.39	6.39	675.5	-6.39	6.39	612.3	-6.39	6.39	546.0	-6.39	6.39	478.8	-6.39	6.39	412.5
MAR 21 SEP 23	-6.00	6.00	568.2	-6.00	6.00	495.2	-6.00	6.00	420.6	-6.00	6.00	346.5	-6.00	6.00	274.8
MAR 7 OCT 8	-5.52	5.52	462.6	-5.41	5.41	382.7	-5.27	5.27	303.1	-5.07	5.07	225.9	-4.78	4.78	153.4
FEB 20 OCT 22	-5.06	5.06	366.2	-4.83	4.83	283.2	-4.54	4.54	202.9	-4.12	4.12	128.4	-3.47	3.47	63.2
FEB 7 NOV 5	-4.62	4.62	284.2	-4.28	4.28	201.5	-3.82	3.82	124.7	-3.13	3.13	58.2	-1.82	1.82	9.6
JAN 23 NOV 19	-4.24	4.24	221.6	-3.79	3.79	141.5	-3.15	3.15	70.9	-2.05	2.05	16.8	0.00	0.00	0.0
JAN 10 DEC 3	-3.95	3.95	179.8	-3.40	3.40	103.0	-2.57	2.57	39.2	-.58	.58	.4	0.00	0.00	0.0
DEC 22	-3.77	3.77	156.4	-3.16	3.16	82.3	-2.17	2.17	23.7	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 213.087		R.I. .4054	YEAR 191.457		R.I. .3643	YEAR 169.984		R.I. .3234	YEAR 150.335		R.I. .2860	YEAR 133.926		R.I. .2548

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 77.0		ALPHA 0.0	THETA 81.0		ALPHA 0.0	THETA 84.7		ALPHA 0.0	THETA 88.0		ALPHA 0.0	THETA 89.0		ALPHA 180.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.78	866.5	-7.78	7.78	826.0	-7.78	7.78	785.6	-7.78	7.78	746.3	-7.78	7.78	708.0
JUN 1 JUL 12	-7.65	7.65	817.7	-7.65	7.65	774.9	-7.65	7.65	732.6	-7.65	7.65	691.8	-7.65	7.65	653.0
MAY 18 JUL 27	-7.42	7.42	736.0	-7.42	7.42	689.6	-7.42	7.42	644.4	-7.42	7.42	601.2	-7.42	7.42	560.1
MAY 3 AUG 10	-7.12	7.12	624.1	-7.12	7.12	573.0	-7.12	7.12	524.1	-7.12	7.12	478.0	-7.12	7.12	434.7
APR 19 AUG 25	-6.77	6.77	491.1	-6.77	6.77	435.1	-6.77	6.77	382.4	-6.77	6.77	333.4	-6.77	6.77	287.9
APR 4 SEP 9	-6.39	6.39	348.8	-6.39	6.39	288.5	-6.39	6.39	232.6	-6.39	6.39	181.1	-6.39	6.39	133.7
MAR 21 SEP 23	-6.00	6.00	206.8	-6.00	6.00	143.5	-6.00	6.00	85.3	-6.00	6.00	32.3	0.00	0.00	0.0
MAR 7 OCT 8	-4.32	4.32	87.7	-3.43	3.43	32.1	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
FEB 20 OCT 22	-2.24	2.24	13.4	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
FEB 7 NOV 5	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 119.727		R.I. .2278	YEAR 107.393		R.I. .2043	YEAR 96.596		R.I. .1838	YEAR 87.320		R.I. .1661	YEAR 79.084		R.I. .1505

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 46 N
ASPECT S -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	40.3	0.0		34.7	0.0		29.3	0.0		24.2	0.0		19.4	0.0	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.44	7.44	1022.9	-7.17	7.17	1016.1	-6.94	6.94	1003.0	-6.75	6.75	984.4	-6.59	6.59	961.5
JUN 1 JUL 12	-7.33	7.33	1004.1	-7.08	7.08	1002.1	-6.87	6.87	993.4	-6.70	6.70	978.8	-6.55	6.55	959.4
MAY 18 JUL 27	-7.15	7.15	971.0	-6.94	6.94	977.0	-6.76	6.76	975.7	-6.60	6.60	967.9	-6.47	6.47	954.6
MAY 3 AUG 10	-6.91	6.91	922.5	-6.74	6.74	939.2	-6.60	6.60	948.1	-6.48	6.48	949.5	-6.38	6.38	944.8
APR 19 AUG 25	-6.63	6.63	859.1	-6.51	6.51	888.4	-6.41	6.41	909.2	-6.33	6.33	921.8	-6.26	6.26	927.4
APR 4 SEP 9	-6.32	6.32	784.0	-6.26	6.26	826.3	-6.21	6.21	859.6	-6.17	6.17	884.4	-6.13	6.13	901.2
MAR 21 SEP 23	-6.00	6.00	699.6	-6.00	6.00	754.1	-6.00	6.00	799.8	-6.00	6.00	836.5	-6.00	6.00	864.9
MAR 7 OCT 8	-5.61	5.61	612.1	-5.61	5.61	676.8	-5.61	5.61	733.0	-5.61	5.61	780.2	-5.61	5.61	818.8
FEB 20 OCT 22	-5.23	5.23	527.5	-5.23	5.23	599.5	-5.23	5.23	663.4	-5.23	5.23	718.5	-5.23	5.23	764.8
FEB 7 NOV 5	-4.88	4.88	451.4	-4.88	4.88	527.8	-4.88	4.88	596.4	-4.88	4.88	656.6	-4.88	4.88	708.2
JAN 23 NOV 19	-4.58	4.58	390.1	-4.58	4.58	468.4	-4.58	4.58	539.4	-4.58	4.58	602.3	-4.58	4.58	656.8
JAN 10 DEC 3	-4.35	4.35	347.2	-4.35	4.35	425.8	-4.35	4.35	497.6	-4.35	4.35	561.5	-4.35	4.35	617.3
DEC 22	-4.22	4.22	322.2	-4.22	4.22	400.7	-4.22	4.22	472.5	-4.22	4.22	536.7	-4.22	4.22	592.9
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	252.557	.4805		268.873	.5116		282.381	.5373		293.061	.5576		301.084	.5728	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	15.0	0.0		11.0	0.0		7.3	0.0		4.0	0.0		1.0	0.0	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.45	6.45	935.6	-6.32	6.32	907.8	-6.21	6.21	879.4	-6.12	6.12	851.2	-6.03	6.03	823.5
JUN 1 JUL 12	-6.41	6.41	936.7	-6.30	6.30	911.7	-6.20	6.20	885.7	-6.11	6.11	859.6	-6.03	6.03	833.7
MAY 18 JUL 27	-6.36	6.36	937.2	-6.26	6.26	917.1	-6.17	6.17	895.3	-6.09	6.09	872.8	-6.02	6.02	850.1
MAY 3 AUG 10	-6.29	6.29	935.1	-6.21	6.21	921.7	-6.14	6.14	905.9	-6.07	6.07	888.7	-6.02	6.02	870.6
APR 19 AUG 25	-6.20	6.20	927.1	-6.14	6.14	922.2	-6.09	6.09	913.9	-6.05	6.05	903.3	-6.01	6.01	891.1
APR 4 SEP 9	-6.10	6.10	911.3	-6.07	6.07	915.9	-6.05	6.05	916.2	-6.03	6.03	913.2	-6.01	6.01	907.9
MAR 21 SEP 23	-6.00	6.00	885.7	-6.00	6.00	900.3	-6.00	6.00	909.6	-6.00	6.00	914.8	-6.00	6.00	917.0
MAR 7 OCT 8	-5.61	5.61	849.4	-5.61	5.61	873.0	-5.61	5.61	890.8	-5.61	5.61	903.7	-5.61	5.61	912.8
FEB 20 OCT 22	-5.23	5.23	803.0	-5.23	5.23	833.7	-5.23	5.23	858.1	-5.23	5.23	877.2	-5.23	5.23	892.0
FEB 7 NOV 5	-4.88	4.88	751.5	-4.88	4.88	787.2	-4.88	4.88	816.4	-4.88	4.88	839.9	-4.88	4.88	858.8
JAN 23 NOV 19	-4.58	4.58	703.1	-4.58	4.58	741.8	-4.58	4.58	773.9	-4.58	4.58	800.2	-4.58	4.58	821.8
JAN 10 DEC 3	-4.35	4.35	665.0	-4.35	4.35	705.3	-4.35	4.35	738.9	-4.35	4.35	766.7	-4.35	4.35	789.7
DEC 22	-4.22	4.22	641.1	-4.22	4.22	682.0	-4.22	4.22	716.2	-4.22	4.22	744.7	-4.22	4.22	768.4
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	306.747	.5836		310.433	.5906		312.515	.5946		313.348	.5962		313.235	.5960	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 46 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	51.2		3.5	56.2		7.8	60.9		13.1	65.0		19.6	68.5		27.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.78	1016.5	-7.78	7.78	999.7	-7.78	7.78	974.6	-7.78	7.78	942.9	-7.78	7.78	906.5
JUN 1 JUL 12	-7.65	7.65	987.5	-7.65	7.65	966.2	-7.65	7.65	937.0	-7.65	7.65	901.8	-7.65	7.65	862.4
MAY 18 JUL 27	-7.42	7.42	937.8	-7.42	7.42	909.2	-7.42	7.42	873.4	-7.42	7.42	832.5	-7.42	7.42	788.2
MAY 3 AUG 10	-7.12	7.12	867.3	-7.12	7.12	829.0	-7.12	7.12	784.8	-7.12	7.12	736.4	-7.12	7.12	686.0
APR 19 AUG 25	-6.77	6.69	779.2	-6.77	6.60	730.5	-6.77	6.48	677.3	-6.77	6.32	621.6	-6.77	6.10	565.6
APR 4 SEP 9	-6.39	6.24	679.8	-6.39	6.05	621.4	-6.39	5.81	560.4	-6.39	5.50	499.1	-6.39	5.11	439.7
MAR 21 SEP 23	-6.00	5.77	573.7	-6.00	5.48	507.4	-6.00	5.13	440.8	-6.00	4.69	376.4	-6.00	4.14	316.7
MAR 7 OCT 8	-5.61	5.30	469.1	-5.61	4.92	397.5	-5.61	4.45	328.0	-5.61	3.88	263.5	-5.61	3.18	206.4
FEB 20 OCT 22	-5.23	4.84	373.2	-5.23	4.36	299.1	-5.23	3.78	229.7	-5.23	3.06	167.9	-5.23	2.19	116.3
FEB 7 NOV 5	-4.88	4.41	291.4	-4.87	3.84	217.4	-4.87	3.13	150.5	-4.86	2.24	93.8	-4.85	1.14	50.0
JAN 23 NOV 19	-4.51	4.04	228.7	-4.41	3.37	156.6	-4.27	2.53	94.0	-4.06	1.44	44.3	-3.66	-.05	11.2
JAN 10 DEC 3	-4.22	3.76	186.8	-4.04	3.01	117.3	-3.78	2.04	59.4	-3.32	.70	17.5	0.00	0.00	0.0
DEC 22	-4.05	3.58	163.2	-3.81	2.78	95.9	-3.45	1.71	41.7	-2.73	.11	6.2	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	214.724		.4085	194.952		.3709	175.428		.3338	157.160		.2990	141.375		.2690

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	71.3		37.8	73.2		49.4	74.3		62.0	74.6		74.3	74.3		85.5
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.78	867.3	-7.78	7.78	826.9	-7.78	7.78	786.6	-7.78	7.78	747.4	-7.78	7.78	709.5
JUN 1 JUL 12	-7.65	7.65	820.7	-7.65	7.65	778.2	-7.65	7.65	736.3	-7.65	7.65	695.7	-7.65	7.65	656.8
MAY 18 JUL 27	-7.42	7.42	742.5	-7.42	7.42	696.8	-7.42	7.42	652.2	-7.42	7.42	609.6	-7.42	7.42	569.1
MAY 3 AUG 10	-7.12	7.12	635.2	-7.12	7.12	585.4	-7.12	7.12	537.6	-7.12	7.12	492.4	-7.12	5.73	450.1
APR 19 AUG 25	-6.77	5.79	510.9	-6.77	5.35	459.2	-6.77	4.75	412.0	-6.77	4.00	370.5	-6.77	3.18	335.2
APR 4 SEP 9	-6.39	4.61	384.3	-6.39	3.98	334.4	-6.39	3.24	291.5	-6.39	2.44	256.2	-6.39	1.66	227.9
MAR 21 SEP 23	-6.00	3.48	263.6	-6.00	2.70	218.6	-6.00	1.87	182.5	-6.00	1.04	154.8	-6.00	.30	134.2
MAR 7 OCT 8	-5.61	2.35	158.6	-5.61	1.43	121.2	-5.61	.50	93.8	-5.61	-.35	74.9	-5.61	-1.07	62.0
FEB 20 OCT 22	-5.23	1.17	76.5	-5.23	.06	48.9	-5.23	-1.02	31.6	-5.23	-1.91	21.8	-5.23	-2.58	16.4
FEB 7 NOV 5	-4.83	-.21	20.6	-4.79	-1.80	5.2	-4.64	-3.63	.2	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	127.979		.2435	116.361		.2214	106.315		.2023	97.686		.1859	90.173		.1716

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 46 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	40.7		2.9	35.4		5.3	30.3		7.3	25.4		9.1	20.9		10.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.66	7.27	1023.2	-7.55	6.85	1017.4	-7.47	6.49	1006.0	-7.40	6.19	989.5	-7.34	5.93	969.0
JUN 1 JUL 12	-7.54	7.16	1004.0	-7.46	6.76	1002.7	-7.40	6.42	995.5	-7.34	6.13	982.9	-7.29	5.89	965.9
MAY 18 JUL 27	-7.36	6.98	970.3	-7.32	6.61	976.7	-7.28	6.30	976.5	-7.24	6.04	970.4	-7.22	5.81	959.2
MAY 3 AUG 10	-7.12	6.73	921.0	-7.11	6.41	937.5	-7.11	6.14	947.0	-7.11	5.90	949.8	-7.11	5.70	946.8
APR 19 AUG 25	-6.77	6.44	856.7	-6.77	6.17	884.9	-6.77	5.94	905.6	-6.77	5.75	918.9	-6.77	5.58	925.7
APR 4 SEP 9	-6.39	6.13	780.5	-6.39	5.92	820.6	-6.39	5.73	852.6	-6.39	5.58	876.8	-6.39	5.44	893.7
MAR 21 SEP 23	-6.00	5.81	695.1	-6.00	5.65	745.9	-6.00	5.51	788.6	-6.00	5.40	823.0	-6.00	5.30	849.6
MAR 7 OCT 8	-5.61	5.48	606.5	-5.61	5.38	666.3	-5.61	5.29	717.9	-5.61	5.22	761.2	-5.61	5.15	796.3
FEB 20 OCT 22	-5.23	5.17	521.4	-5.23	5.12	587.5	-5.23	5.08	645.9	-5.23	5.05	696.0	-5.23	5.02	737.9
FEB 7 NOV 5	-4.88	4.88	445.0	-4.88	4.88	515.2	-4.88	4.88	577.9	-4.88	4.88	632.7	-4.88	4.88	679.4
JAN 23 NOV 19	-4.58	4.58	383.6	-4.58	4.58	455.6	-4.58	4.58	520.7	-4.58	4.58	578.1	-4.58	4.58	627.7
JAN 10 DEC 3	-4.35	4.35	340.7	-4.35	4.35	413.1	-4.35	4.35	478.9	-4.35	4.35	537.4	-4.35	4.35	588.3
DEC 22	-4.22	4.22	315.8	-4.22	4.22	388.0	-4.22	4.22	454.0	-4.22	4.22	512.7	-4.22	4.22	564.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	251.173		.4779	266.355		.5068	278.962		.5307	288.946		.5497	296.450		.5640

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	16.7		11.9	12.8		13.0	9.2		14.0	6.1		14.9	3.1		15.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.29	5.71	945.6	-7.24	5.51	920.5	-7.21	5.34	894.6	-7.17	5.18	868.8	-7.14	5.04	843.4
JUN 1 JUL 12	-7.25	5.67	945.6	-7.22	5.48	923.2	-7.19	5.32	899.7	-7.16	5.17	875.9	-7.13	5.04	852.3
MAY 18 JUL 27	-7.19	5.61	944.2	-7.17	5.44	926.4	-7.15	5.28	907.0	-7.14	5.15	886.9	-7.12	5.03	866.4
MAY 3 AUG 10	-7.11	5.53	939.2	-7.11	5.37	928.1	-7.11	5.24	914.6	-7.11	5.12	899.6	-7.11	5.01	883.7
APR 19 AUG 25	-6.77	5.43	926.9	-6.77	5.30	923.8	-6.77	5.19	917.4	-6.77	5.08	908.8	-6.77	4.99	898.5
APR 4 SEP 9	-6.39	5.32	904.3	-6.39	5.22	909.7	-6.39	5.13	910.9	-6.39	5.05	909.0	-6.39	4.97	904.9
MAR 21 SEP 23	-6.00	5.21	869.3	-6.00	5.13	882.9	-6.00	5.07	891.7	-6.00	5.01	896.6	-6.00	4.95	898.6
MAR 7 OCT 8	-5.61	5.10	823.9	-5.61	5.05	845.1	-5.61	5.00	860.8	-5.61	4.97	871.9	-5.61	4.93	879.6
FEB 20 OCT 22	-5.23	4.99	772.0	-5.23	4.97	799.3	-5.23	4.95	820.8	-5.23	4.93	837.3	-5.23	4.91	849.8
FEB 7 NOV 5	-4.88	4.88	718.3	-4.88	4.88	750.3	-4.88	4.88	776.2	-4.88	4.88	796.8	-4.88	4.88	813.3
JAN 23 NOV 19	-4.58	4.58	669.5	-4.58	4.58	704.5	-4.58	4.58	733.2	-4.58	4.58	756.6	-4.58	4.58	775.7
JAN 10 DEC 3	-4.35	4.35	631.6	-4.35	4.35	668.0	-4.35	4.35	698.3	-4.35	4.35	723.2	-4.35	4.35	743.8
DEC 22	-4.22	4.22	607.9	-4.22	4.22	645.0	-4.22	4.22	675.9	-4.22	4.22	701.5	-4.22	4.22	722.8
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	301.741		.5741	305.175		.5806	307.099		.5843	307.847		.5857	307.705		.5854

NOTE - FOR ASPECTS WITH WEST COMPONENTS. THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 46 N
ASPECT NE - NW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	49.9		6.3	53.3		13.4	56.1		21.4	58.2		29.9	59.7		38.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.65	1017.1	-7.78	7.48	1001.2	-7.78	7.26	977.5	-7.78	6.98	947.8	-7.78	6.61	914.3
JUN 1 JUL 12	-7.65	7.49	989.3	-7.65	7.29	970.3	-7.65	7.04	944.0	-7.65	6.72	912.4	-7.65	6.32	877.8
MAY 18 JUL 27	-7.42	7.22	941.7	-7.42	6.98	917.7	-7.42	6.67	887.4	-7.42	6.31	853.0	-7.42	5.87	816.7
MAY 3 AUG 10	-7.12	6.87	873.9	-7.12	6.57	843.5	-7.12	6.21	808.3	-7.12	5.79	770.7	-7.12	5.31	732.7
APR 19 AUG 25	-6.77	6.46	789.0	-6.77	6.10	751.7	-6.77	5.69	711.7	-6.77	5.22	671.1	-6.77	4.70	632.0
APR 4 SEP 9	-6.39	6.03	692.6	-6.39	5.61	649.0	-6.39	5.14	604.9	-6.39	4.62	562.3	-6.39	4.06	523.0
MAR 21 SEP 23	-6.00	5.58	589.2	-6.00	5.11	540.6	-6.00	4.58	493.7	-6.00	4.00	450.5	-6.00	3.42	412.2
MAR 7 OCT 8	-5.61	5.13	486.6	-5.61	4.60	434.8	-5.61	4.01	386.9	-5.61	3.39	344.5	-5.61	2.77	308.5
FEB 20 OCT 22	-5.23	4.70	392.1	-5.23	4.11	339.0	-5.23	3.46	291.7	-5.23	2.79	251.5	-5.23	2.13	218.9
FEB 7 NOV 5	-4.88	4.29	311.0	-4.88	3.64	258.2	-4.88	2.94	212.9	-4.88	2.22	176.0	-4.88	1.52	147.4
JAN 23 NOV 19	-4.58	3.94	248.3	-4.58	3.23	197.0	-4.58	2.48	154.4	-4.58	1.70	121.1	-4.58	.96	96.5
JAN 10 DEC 3	-4.35	3.68	206.1	-4.35	2.92	156.5	-4.35	2.11	116.5	-4.35	1.29	86.3	-4.35	.51	65.0
DEC 22	-4.22	3.51	182.3	-4.22	2.73	134.0	-4.22	1.89	95.8	-4.22	1.03	67.7	-4.22	.22	48.6
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	219.319		.4173	204.609		.3893	190.338		.3621	177.061		.3369	165.147		.3142

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	60.4		47.5	60.6		55.6	60.3		63.1	59.7		69.6	58.9		75.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	6.17	879.2	-7.78	5.65	844.5	-7.78	5.11	811.8	-7.78	4.56	781.8	-7.78	4.05	754.8
JUN 1 JUL 12	-7.65	5.85	842.2	-7.65	5.33	807.6	-7.65	4.80	775.3	-7.65	4.27	746.0	-7.65	3.78	719.8
MAY 18 JUL 27	-7.42	5.38	780.6	-7.42	4.85	746.2	-7.42	4.33	714.8	-7.42	3.82	686.7	-7.42	3.35	661.8
MAY 3 AUG 10	-7.12	4.80	696.3	-7.12	4.27	662.6	-7.12	3.75	632.6	-7.12	3.26	606.2	-7.12	2.82	583.2
APR 19 AUG 25	-6.77	4.16	595.9	-6.77	3.62	563.6	-6.77	3.11	535.5	-6.77	2.65	511.5	-6.77	2.22	490.9
APR 4 SEP 9	-6.39	3.50	488.1	-6.39	2.96	457.9	-6.39	2.46	432.5	-6.39	2.01	411.3	-6.39	1.61	393.4
MAR 21 SEP 23	-6.00	2.84	379.6	-6.00	2.29	352.4	-6.00	1.80	330.2	-6.00	1.36	312.2	-6.00	.98	297.4
MAR 7 OCT 8	-5.61	2.17	279.1	-5.61	1.62	255.6	-5.61	1.13	237.0	-5.61	.71	222.4	-5.61	.36	210.7
FEB 20 OCT 22	-5.23	1.51	193.4	-5.23	.96	173.9	-5.23	.48	159.1	-5.23	.08	147.8	-5.23	-.26	139.0
FEB 7 NOV 5	-4.88	.88	126.1	-4.88	.32	110.6	-4.88	-.15	99.4	-4.88	-.54	91.1	-4.88	-.85	85.0
JAN 23 NOV 19	-4.58	.29	79.2	-4.58	-.27	67.2	-4.58	-.73	59.0	-4.58	-1.10	53.3	-4.58	-1.39	49.1
JAN 10 DEC 3	-4.35	-.18	50.8	-4.35	-.75	41.5	-4.35	-1.20	35.5	-4.35	-1.55	31.5	-4.35	-1.81	28.8
DEC 22	-4.22	-.49	36.3	-4.22	-1.07	28.7	-4.22	-1.51	24.0	-4.22	-1.84	21.0	-4.22	-2.09	19.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	154.747		.2944	145.821		.2774	138.256		.2630	131.882		.2509	126.467		.2406

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 46 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	41.8	5.4		37.5	10.1		33.2	14.1		29.0	17.5		25.1	20.4	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.16	1023.6	-7.78	6.63	1020.0	-7.78	6.17	1012.5	-7.78	5.77	1001.1	-7.78	5.42	986.4
JUN 1 JUL 12	-7.65	7.05	1003.3	-7.65	6.53	1003.4	-7.65	6.08	999.3	-7.65	5.70	991.0	-7.65	5.36	979.3
MAY 18 JUL 27	-7.42	6.86	967.9	-7.42	6.37	973.9	-7.42	5.95	975.5	-7.42	5.58	972.4	-7.42	5.27	965.4
MAY 3 AUG 10	-7.12	6.60	916.1	-7.12	6.15	930.1	-7.12	5.76	939.1	-7.12	5.43	943.0	-7.12	5.14	942.4
APR 19 AUG 25	-6.77	6.30	848.9	-6.77	5.90	871.9	-6.77	5.55	889.4	-6.77	5.24	901.3	-6.77	4.98	908.0
APR 4 SEP 9	-6.39	5.98	770.0	-6.39	5.62	801.8	-6.39	5.31	827.9	-6.39	5.04	847.9	-6.39	4.81	862.2
MAR 21 SEP 23	-6.00	5.64	681.9	-6.00	5.33	721.8	-6.00	5.06	755.7	-6.00	4.83	783.3	-6.00	4.64	804.6
MAR 7 OCT 8	-5.61	5.30	591.3	-5.61	5.04	637.7	-5.61	4.82	678.1	-5.61	4.63	711.8	-5.61	4.46	739.2
FEB 20 OCT 22	-5.23	4.98	504.6	-5.23	4.76	555.6	-5.23	4.58	600.6	-5.23	4.42	639.0	-5.23	4.29	670.9
FEB 7 NOV 5	-4.88	4.67	427.2	-4.88	4.50	480.9	-4.88	4.36	528.7	-4.88	4.24	570.2	-4.88	4.14	605.2
JAN 23 NOV 19	-4.58	4.42	365.4	-4.58	4.29	420.2	-4.58	4.18	469.4	-4.58	4.09	512.4	-4.58	4.01	549.2
JAN 10 DEC 3	-4.35	4.23	322.4	-4.35	4.13	377.4	-4.35	4.04	427.0	-4.35	3.97	470.6	-4.35	3.91	508.2
DEC 22	-4.22	4.11	297.6	-4.22	4.03	352.3	-4.22	3.96	401.9	-4.22	3.90	445.7	-4.22	3.86	483.6
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	247.186	.4703		259.035	.4928		268.947	.5117		276.813	.5267		282.705	.5379	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	21.4	23.0		17.9	25.2		14.8	27.2		11.9	28.9		9.3	30.4	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	5.12	969.3	-7.78	4.86	950.5	-7.78	4.63	930.9	-7.78	4.42	911.0	-7.78	4.24	891.2
JUN 1 JUL 12	-7.65	5.07	964.7	-7.65	4.82	948.2	-7.65	4.59	930.6	-7.65	4.40	912.5	-7.65	4.22	894.3
MAY 18 JUL 27	-7.42	4.99	955.2	-7.42	4.75	942.5	-7.42	4.54	928.2	-7.42	4.36	913.1	-7.42	4.19	897.5
MAY 3 AUG 10	-7.12	4.88	937.9	-7.12	4.66	930.4	-7.12	4.47	920.7	-7.12	4.30	909.6	-7.12	4.14	897.6
APR 19 AUG 25	-6.77	4.76	910.2	-6.77	4.56	908.7	-6.77	4.38	904.4	-6.77	4.23	898.1	-6.77	4.09	890.3
APR 4 SEP 9	-6.39	4.61	871.3	-6.39	4.44	876.1	-6.39	4.29	877.4	-6.39	4.15	876.1	-6.39	4.03	872.9
MAR 21 SEP 23	-6.00	4.47	820.2	-6.00	4.32	831.0	-6.00	4.19	837.9	-6.00	4.07	841.5	-6.00	3.97	842.7
MAR 7 OCT 8	-5.61	4.32	760.5	-5.61	4.20	776.6	-5.61	4.09	788.3	-5.61	3.99	796.3	-5.61	3.91	801.6
FEB 20 OCT 22	-5.23	4.18	696.6	-5.23	4.08	717.0	-5.23	3.99	732.6	-5.23	3.92	744.3	-5.23	3.85	753.0
FEB 7 NOV 5	-4.88	4.05	634.0	-4.88	3.97	657.3	-4.88	3.91	675.8	-4.88	3.85	690.3	-4.88	3.80	701.6
JAN 23 NOV 19	-4.58	3.94	579.8	-4.58	3.88	605.1	-4.58	3.83	625.5	-4.58	3.79	641.8	-4.58	3.75	654.8
JAN 10 DEC 3	-4.35	3.86	539.8	-4.35	3.82	566.0	-4.35	3.78	587.5	-4.35	3.75	604.9	-4.35	3.72	619.0
DEC 22	-4.22	3.81	515.6	-4.22	3.78	542.3	-4.22	3.75	564.2	-4.22	3.72	582.2	-4.22	3.70	596.8
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	286.809	.5457		289.402	.5506		290.761	.5532		291.157	.5540		290.823	.5533	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 46 N
ASPECT ENE - WNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 47.9		ALPHA 7.9	THETA 49.2		ALPHA 16.1	THETA 49.9		ALPHA 24.4	THETA 50.1		ALPHA 32.3	THETA 49.7		ALPHA 39.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.39	1018.9	-7.78	6.95	1007.3	-7.78	6.45	990.5	-7.78	5.93	970.5	-7.78	5.41	948.8
JUN 1 JUL 12	-7.65	7.24	993.0	-7.65	6.79	980.1	-7.65	6.29	962.6	-7.65	5.77	942.2	-7.65	5.25	920.6
MAY 18 JUL 27	-7.42	7.00	948.3	-7.42	6.53	933.4	-7.42	6.02	914.6	-7.42	5.50	893.8	-7.42	4.98	872.4
MAY 3 AUG 10	-7.12	6.67	884.4	-7.12	6.18	866.8	-7.12	5.67	846.7	-7.12	5.14	825.5	-7.12	4.63	804.4
APR 19 AUG 25	-6.77	6.30	803.7	-6.77	5.79	783.4	-6.77	5.26	761.9	-6.77	4.73	740.5	-6.77	4.23	720.1
APR 4 SEP 9	-6.39	5.89	711.5	-6.39	5.36	688.6	-6.39	4.82	666.1	-6.39	4.30	644.9	-6.39	3.80	625.5
MAR 21 SEP 23	-6.00	5.47	611.7	-6.00	4.93	586.9	-6.00	4.38	563.9	-6.00	3.85	543.3	-6.00	3.36	525.2
MAR 7 OCT 8	-5.61	5.06	511.9	-5.61	4.49	486.0	-5.61	3.93	463.1	-5.61	3.40	443.6	-5.61	2.91	427.2
FEB 20 OCT 22	-5.23	4.65	419.1	-5.23	4.06	392.9	-5.23	3.49	370.8	-5.23	2.96	352.7	-5.23	2.48	338.1
FEB 7 NOV 5	-4.88	4.27	338.7	-4.88	3.67	312.9	-4.88	3.08	291.9	-4.88	2.55	275.4	-4.88	2.08	262.7
JAN 23 NOV 19	-4.58	3.95	276.1	-4.58	3.32	251.1	-4.58	2.73	231.5	-4.58	2.20	216.5	-4.58	1.73	205.3
JAN 10 DEC 3	-4.35	3.70	233.5	-4.35	3.06	209.4	-4.35	2.46	190.9	-4.35	1.93	177.2	-4.35	1.46	167.2
DEC 22	-4.22	3.55	209.4	-4.22	2.90	185.9	-4.22	2.30	168.2	-4.22	1.76	155.2	-4.22	1.30	146.0
	YEAR 226.023		R.I. .4300	YEAR 218.306		R.I. .4153	YEAR 210.937		R.I. .4013	YEAR 204.119		R.I. .3884	YEAR 197.953		R.I. .3766

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 48.9		ALPHA 46.3	THETA 47.9		ALPHA 52.2	THETA 46.7		ALPHA 57.3	THETA 45.4		ALPHA 61.7	THETA 44.2		ALPHA 65.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	4.91	926.9	-7.78	4.44	905.7	-7.78	4.01	885.6	-7.78	3.63	866.9	-7.78	3.29	849.5
JUN 1 JUL 12	-7.65	4.75	899.0	-7.65	4.29	878.2	-7.65	3.87	858.7	-7.65	3.50	840.5	-7.65	3.16	823.7
MAY 18 JUL 27	-7.42	4.49	851.4	-7.42	4.04	831.4	-7.42	3.64	812.8	-7.42	3.28	795.6	-7.42	2.96	779.8
MAY 3 AUG 10	-7.12	4.16	784.2	-7.12	3.72	765.4	-7.12	3.33	748.1	-7.12	2.98	732.3	-7.12	2.68	717.8
APR 19 AUG 25	-6.77	3.76	701.1	-6.77	3.34	683.8	-6.77	2.97	668.2	-6.77	2.64	654.0	-6.77	2.35	641.2
APR 4 SEP 9	-6.39	3.35	608.0	-6.39	2.94	592.5	-6.39	2.58	578.7	-6.39	2.27	566.5	-6.39	1.99	555.5
MAR 21 SEP 23	-6.00	2.91	509.6	-6.00	2.52	496.1	-6.00	2.18	484.3	-6.00	1.88	474.1	-6.00	1.63	465.0
MAR 7 OCT 8	-5.61	2.48	413.5	-5.61	2.10	402.0	-5.61	1.78	392.3	-5.61	1.50	384.0	-5.61	1.26	376.7
FEB 20 OCT 22	-5.23	2.06	326.3	-5.23	1.70	316.8	-5.23	1.39	309.0	-5.23	1.13	302.4	-5.23	.91	296.8
FEB 7 NOV 5	-4.88	1.67	252.8	-4.88	1.32	245.0	-4.88	1.03	238.8	-4.88	.79	233.7	-4.88	.58	229.4
JAN 23 NOV 19	-4.58	1.33	196.9	-4.58	1.00	190.6	-4.58	.72	185.6	-4.58	.49	181.7	-4.58	.30	178.4
JAN 10 DEC 3	-4.35	1.08	159.9	-4.35	.75	154.5	-4.35	.49	150.4	-4.35	.27	147.2	-4.35	.09	144.6
DEC 22	-4.22	.92	139.3	-4.22	.60	134.5	-4.22	.35	130.9	-4.22	.14	128.1	-4.22	-.04	125.8
	YEAR 192.447		R.I. .3661	YEAR 187.549		R.I. .3568	YEAR 183.198		R.I. .3486	YEAR 179.323		R.I. .3412	YEAR 175.828		R.I. .3345

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 46 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	43.6		7.3	40.8		13.9	37.8		19.6	34.7		24.7	31.6		29.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.14	1023.0	-7.78	6.55	1019.5	-7.78	6.00	1013.3	-7.78	5.52	1004.3	-7.78	5.10	993.0
JUN 1 JUL 12	-7.65	7.02	1001.1	-7.65	6.43	999.8	-7.65	5.91	995.7	-7.65	5.44	988.8	-7.65	5.02	979.5
MAY 18 JUL 27	-7.42	6.81	962.9	-7.42	6.25	965.3	-7.42	5.74	964.7	-7.42	5.29	961.2	-7.42	4.90	955.0
MAY 3 AUG 10	-7.12	6.54	907.5	-7.12	6.00	914.7	-7.12	5.52	918.8	-7.12	5.10	919.8	-7.12	4.72	917.8
APR 19 AUG 25	-6.77	6.22	836.4	-6.77	5.71	848.9	-6.77	5.26	858.3	-6.77	4.87	864.4	-6.77	4.52	867.2
APR 4 SEP 9	-6.39	5.87	753.4	-6.39	5.40	771.2	-6.39	4.98	785.9	-6.39	4.62	797.1	-6.39	4.30	804.8
MAR 21 SEP 23	-6.00	5.51	661.7	-6.00	5.08	684.3	-6.00	4.69	703.8	-6.00	4.36	719.7	-6.00	4.06	731.8
MAR 7 OCT 8	-5.61	5.15	568.2	-5.61	4.75	594.6	-5.61	4.40	617.9	-5.61	4.09	637.6	-5.61	3.83	653.4
FEB 20 OCT 22	-5.23	4.81	479.6	-5.23	4.44	508.5	-5.23	4.12	534.5	-5.23	3.84	556.9	-5.23	3.61	575.4
FEB 7 NOV 5	-4.88	4.49	401.1	-4.88	4.15	431.5	-4.88	3.86	459.1	-4.88	3.61	483.1	-4.88	3.40	503.3
JAN 23 NOV 19	-4.58	4.21	338.9	-4.58	3.90	369.8	-4.58	3.64	398.0	-4.58	3.42	422.8	-4.58	3.23	443.9
JAN 10 DEC 3	-4.35	4.01	295.9	-4.35	3.72	326.8	-4.35	3.48	355.1	-4.35	3.27	380.0	-4.35	3.11	401.4
DEC 22	-4.22	3.88	271.2	-4.22	3.61	301.9	-4.22	3.38	330.1	-4.22	3.19	355.0	-4.22	3.03	376.4
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	241.087		.4587	247.640		.4712	253.127		.4816	257.412		.4897	260.486		.4956

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	28.7		32.8	25.9		36.1	23.3		38.9	20.9		41.4	18.7		43.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	4.73	980.0	-7.78	4.41	965.7	-7.78	4.12	950.7	-7.78	3.88	935.4	-7.78	3.66	920.1
JUN 1 JUL 12	-7.65	4.66	968.2	-7.65	4.35	955.5	-7.65	4.07	941.8	-7.65	3.83	927.8	-7.65	3.62	913.6
MAY 18 JUL 27	-7.42	4.55	946.6	-7.42	4.25	936.5	-7.42	3.98	925.2	-7.42	3.75	913.3	-7.42	3.55	901.0
MAY 3 AUG 10	-7.12	4.40	913.3	-7.12	4.11	906.7	-7.12	3.86	898.5	-7.12	3.65	889.4	-7.12	3.45	879.6
APR 19 AUG 25	-6.77	4.22	867.1	-6.77	3.95	864.5	-6.77	3.72	860.0	-6.77	3.52	854.2	-6.77	3.34	847.3
APR 4 SEP 9	-6.39	4.02	809.2	-6.39	3.78	810.7	-6.39	3.57	810.0	-6.39	3.38	807.6	-6.39	3.22	803.8
MAR 21 SEP 23	-6.00	3.81	740.3	-6.00	3.59	745.8	-6.00	3.40	748.7	-6.00	3.24	749.6	-6.00	3.09	748.8
MAR 7 OCT 8	-5.61	3.61	665.5	-5.61	3.41	674.3	-5.61	3.24	680.4	-5.61	3.09	684.1	-5.61	2.97	686.0
FEB 20 OCT 22	-5.23	3.41	590.2	-5.23	3.24	601.6	-5.23	3.09	610.1	-5.23	2.96	616.1	-5.23	2.84	620.2
FEB 7 NOV 5	-4.88	3.23	519.8	-4.88	3.08	533.0	-4.88	2.94	543.2	-4.88	2.83	550.9	-4.88	2.73	556.6
JAN 23 NOV 19	-4.58	3.07	461.3	-4.58	2.94	475.5	-4.58	2.82	486.7	-4.58	2.73	495.4	-4.58	2.64	502.2
JAN 10 DEC 3	-4.35	2.96	419.3	-4.35	2.84	433.9	-4.35	2.74	445.6	-4.35	2.65	454.9	-4.35	2.57	462.3
DEC 22	-4.22	2.89	394.4	-4.22	2.78	409.2	-4.22	2.68	421.2	-4.22	2.60	430.7	-4.22	2.53	438.3
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	262.435		.4993	263.418		.5012	263.608		.5015	263.184		.5007	262.294		.4990

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 46 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	45.7	8.2		44.9	16.1		43.6	23.4		41.9	29.9		40.0	35.7	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	7.22	1021.2	-7.78	6.64	1014.7	-7.78	6.07	1005.2	-7.78	5.54	993.3	-7.78	5.05	980.1
JUN 1 JUL 12	-7.65	7.08	997.3	-7.65	6.51	991.4	-7.65	5.95	982.6	-7.65	5.42	971.7	-7.65	4.94	959.3
MAY 18 JUL 27	-7.42	6.86	956.0	-7.42	6.29	950.9	-7.42	5.74	943.3	-7.42	5.23	933.9	-7.42	4.76	923.2
MAY 3 AUG 10	-7.12	6.56	896.4	-7.12	6.00	892.4	-7.12	5.47	886.6	-7.12	4.97	879.2	-7.12	4.52	870.6
APR 19 AUG 25	-6.77	6.21	820.5	-6.77	5.67	818.0	-6.77	5.15	814.1	-6.77	4.67	809.0	-6.77	4.24	802.9
APR 4 SEP 9	-6.39	5.84	732.9	-6.39	5.30	731.8	-6.39	4.80	729.9	-6.39	4.34	727.2	-6.39	3.93	723.7
MAR 21 SEP 23	-6.00	5.45	637.2	-6.00	4.93	637.4	-6.00	4.44	637.4	-6.00	4.00	637.0	-6.00	3.62	635.9
MAR 7 OCT 8	-5.61	5.07	540.5	-5.61	4.55	541.9	-5.61	4.08	543.6	-5.61	3.67	545.2	-5.61	3.30	546.2
FEB 20 OCT 22	-5.23	4.69	449.7	-5.23	4.19	452.0	-5.23	3.74	455.1	-5.23	3.34	458.2	-5.23	2.99	460.9
FEB 7 NOV 5	-4.88	4.35	370.2	-4.88	3.85	373.2	-4.88	3.42	377.2	-4.88	3.04	381.3	-4.88	2.71	385.2
JAN 23 NOV 19	-4.58	4.05	307.7	-4.58	3.57	311.1	-4.58	3.14	315.6	-4.58	2.78	320.5	-4.58	2.47	325.0
JAN 10 DEC 3	-4.35	3.83	264.9	-4.35	3.35	268.5	-4.35	2.94	273.3	-4.35	2.59	278.4	-4.35	2.30	283.3
DEC 22	-4.22	3.69	240.4	-4.22	3.22	244.1	-4.22	2.82	249.0	-4.22	2.47	254.3	-4.22	2.19	259.3
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	233.680	.4446		233.444	.4441		232.998	.4433		232.291	.4420		231.300	.4401	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	38.1	40.8		36.1	45.2		34.2	49.0		32.3	52.3		30.6	55.2	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.78	4.61	965.9	-7.78	4.22	951.3	-7.78	3.88	936.6	-7.78	3.58	922.2	-7.78	3.31	908.1
JUN 1 JUL 12	-7.65	4.51	946.1	-7.65	4.13	932.4	-7.65	3.79	918.6	-7.65	3.50	905.0	-7.65	3.24	891.7
MAY 18 JUL 27	-7.42	4.34	911.6	-7.42	3.97	899.4	-7.42	3.65	887.1	-7.42	3.37	874.8	-7.42	3.12	862.7
MAY 3 AUG 10	-7.12	4.12	861.1	-7.12	3.77	851.1	-7.12	3.46	840.7	-7.12	3.19	830.3	-7.12	2.95	819.9
APR 19 AUG 25	-6.77	3.86	795.9	-6.77	3.52	788.3	-6.77	3.23	780.3	-6.77	2.98	772.0	-6.77	2.76	763.6
APR 4 SEP 9	-6.39	3.57	719.3	-6.39	3.26	714.2	-6.39	2.99	708.6	-6.39	2.75	702.6	-6.39	2.54	696.3
MAR 21 SEP 23	-6.00	3.28	634.1	-6.00	2.98	631.4	-6.00	2.73	628.1	-6.00	2.51	624.3	-6.00	2.32	620.0
MAR 7 OCT 8	-5.61	2.98	546.5	-5.61	2.71	546.0	-5.61	2.47	544.7	-5.61	2.27	542.8	-5.61	2.10	540.4
FEB 20 OCT 22	-5.23	2.70	462.8	-5.23	2.45	464.0	-5.23	2.23	464.4	-5.23	2.04	464.1	-5.23	1.88	463.2
FEB 7 NOV 5	-4.88	2.44	388.4	-4.88	2.20	390.8	-4.88	2.00	392.3	-4.88	1.83	393.2	-4.88	1.69	393.4
JAN 23 NOV 19	-4.58	2.21	328.9	-4.58	2.00	332.1	-4.58	1.81	334.4	-4.58	1.66	336.0	-4.58	1.52	337.0
JAN 10 DEC 3	-4.35	2.05	287.6	-4.35	1.84	291.2	-4.35	1.67	293.9	-4.35	1.53	295.9	-4.35	1.40	297.3
DEC 22	-4.22	1.95	263.8	-4.22	1.75	267.5	-4.22	1.59	270.4	-4.22	1.45	272.7	-4.22	1.33	274.3
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	230.028	.4376		228.508	.4348		226.793	.4315		224.942	.4280		222.993	.4243	

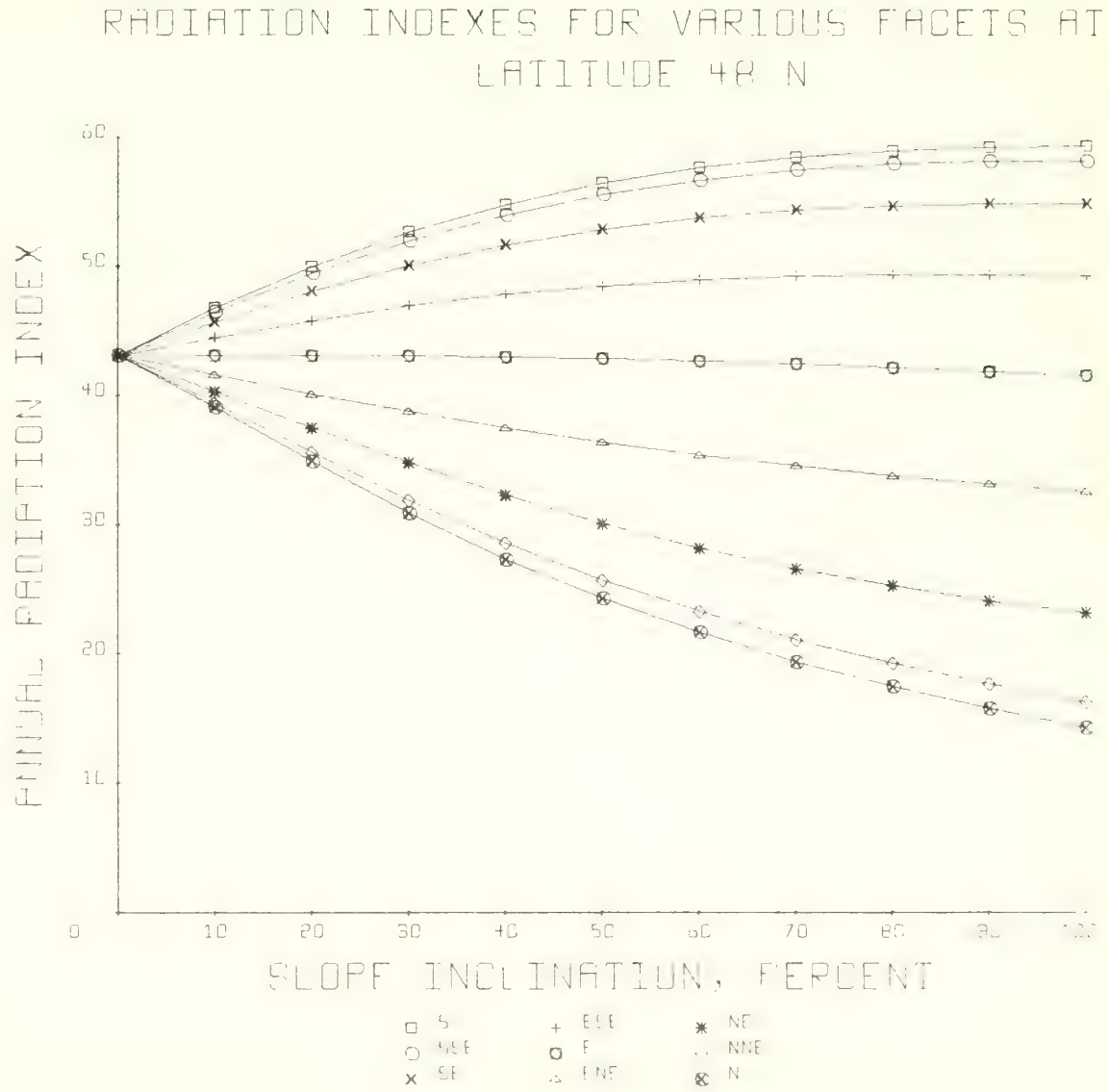
NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 48 N

		SR	SS	LY
JUN 22		-7.93	7.93	1022.5
JUN 1	JUL 12	-7.77	7.77	996.5
MAY 18	JUL 27	-7.53	7.53	951.7
MAY 3	AUG 10	-7.20	7.20	887.5
APR 19	AUG 25	-6.82	6.82	806.5
APR 4	SEP 9	-6.42	6.42	713.9
MAR 21	SEP 23	-6.00	6.00	613.7
MAR 7	OCT 8	-5.58	5.58	513.4
FEB 20	OCT 22	-5.18	5.18	420.2
FEB 7	NOV 5	-4.80	4.80	339.5
JAN 23	NOV 19	-4.47	4.47	276.6
JAN 10	DEC 3	-4.23	4.23	233.8
DEC 22		-4.08	4.08	209.6

YEAR	R.I.
226.745	.4314



LATITUDE 48 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	53.7		0.0	59.3		0.0	64.7		0.0	69.8		0.0	74.6		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.93	1013.6	-7.93	7.93	995.1	-7.93	7.93	968.4	-7.93	7.93	935.2	-7.93	7.93	897.4
JUN 1 JUL 12	-7.77	7.77	982.1	-7.77	7.77	958.5	-7.77	7.77	927.2	-7.77	7.77	890.0	-7.77	7.77	848.8
MAY 18 JUL 27	-7.53	7.53	928.3	-7.53	7.53	896.5	-7.53	7.53	857.9	-7.53	7.53	814.3	-7.53	7.53	767.7
MAY 3 AUG 10	-7.20	7.20	852.5	-7.20	7.20	810.1	-7.20	7.20	762.0	-7.20	7.20	710.2	-7.20	7.20	656.7
APR 19 AUG 25	-6.82	6.82	758.8	-6.82	6.82	704.7	-6.82	6.82	646.3	-6.82	6.82	585.8	-6.82	6.82	525.0
APR 4 SEP 9	-6.42	6.42	653.7	-6.42	6.42	588.5	-6.42	6.42	520.4	-6.42	6.42	451.7	-6.42	6.42	384.3
MAR 21 SEP 23	-6.00	6.00	542.7	-6.00	6.00	468.0	-6.00	6.00	391.9	-6.00	6.00	316.7	-6.00	6.00	244.1
MAR 7 OCT 8	-5.49	5.49	434.5	-5.36	5.36	353.4	-5.20	5.20	272.9	-4.96	4.96	195.4	-4.60	4.60	123.3
FEB 20 OCT 22	-4.98	4.98	336.7	-4.74	4.74	253.3	-4.39	4.39	173.4	-3.89	3.89	100.3	-3.05	3.05	38.6
FEB 7 NOV 5	-4.51	4.51	254.5	-4.13	4.13	172.5	-3.59	3.59	97.6	-2.71	2.71	35.4	0.00	0.00	0.0
JAN 23 NOV 19	-4.10	4.10	192.5	-3.58	3.58	114.2	-2.81	2.81	47.5	-1.17	1.17	2.9	0.00	0.00	0.0
JAN 10 DEC 3	-3.78	3.78	151.6	-3.15	3.15	77.8	-2.10	2.10	20.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-3.58	3.58	129.0	-2.86	2.86	58.5	-1.54	1.54	8.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	205.694		.3914	183.878		.3498	162.577		.3093	143.943		.2739	128.149		.2438

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	79.0		0.0	83.0		0.0	86.7		0.0	90.0		0.0	87.0		180.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.93	857.1	-7.93	7.93	815.6	-7.93	7.93	774.5	-7.93	7.93	736.8	-7.93	7.93	696.4
JUN 1 JUL 12	-7.77	7.77	805.6	-7.77	7.77	761.9	-7.77	7.77	718.8	-7.77	7.77	679.7	-7.77	7.77	637.1
MAY 18 JUL 27	-7.53	7.53	720.0	-7.53	7.53	672.5	-7.53	7.53	626.5	-7.53	7.53	585.1	-7.53	7.53	541.0
MAY 3 AUG 10	-7.20	7.20	603.3	-7.20	7.20	551.2	-7.20	7.20	501.5	-7.20	7.20	457.4	-7.20	7.20	410.6
APR 19 AUG 25	-6.82	6.82	465.6	-6.82	6.82	408.8	-6.82	6.82	355.4	-6.82	6.82	308.7	6.82	6.82	259.6
APR 4 SEP 9	-6.42	6.42	319.6	-6.42	6.42	258.7	-6.42	6.42	202.3	-6.42	6.42	153.4	-6.42	6.42	102.8
MAR 21 SEP 23	-6.00	6.00	175.5	-6.00	6.00	111.8	-6.00	6.00	53.4	-6.00	6.00	3.3	0.00	0.00	0.0
MAR 7 OCT 8	-3.97	3.97	59.2	-2.44	2.44	9.3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
FEB 20 OCT 22	-.56	.56	.2	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
FEB 7 NOV 5	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	114.378		.2176	102.415		.1949	92.143		.1753	83.289		.1585	75.344		.1433

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 48 N
ASPECT S -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	42.3	0.0		36.7	0.0		31.3	0.0		26.2	0.0		21.4	0.0	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.55	7.55	1023.8	-7.26	7.26	1019.3	-7.02	7.02	1008.6	-6.82	6.82	992.4	-6.66	6.66	971.8
JUN 1 JUL 12	-7.43	7.43	1003.2	-7.17	7.17	1003.6	-6.95	6.95	997.4	-6.76	6.76	985.3	-6.61	6.61	968.2
MAY 18 JUL 27	-7.24	7.24	967.2	-7.01	7.01	975.7	-6.82	6.82	977.0	-6.66	6.66	971.7	-6.53	6.53	960.9
MAY 3 AUG 10	-6.98	6.98	914.7	-6.80	6.80	934.1	-6.65	6.65	945.6	-6.53	6.53	949.8	-6.42	6.42	947.5
APR 19 AUG 25	-6.67	6.67	846.8	-6.55	6.55	878.8	-6.45	6.45	902.3	-6.36	6.36	917.7	-6.29	6.29	925.8
APR 4 SEP 9	-6.34	6.34	767.1	-6.28	6.28	812.0	-6.23	6.23	848.1	-6.19	6.19	875.5	-6.15	6.15	894.9
MAR 21 SEP 23	-6.00	6.00	678.5	-6.00	6.00	735.5	-6.00	6.00	783.6	-6.00	6.00	822.9	-6.00	6.00	853.7
MAR 7 OCT 8	-5.58	5.58	587.4	-5.58	5.58	654.2	-5.58	5.58	712.6	-5.58	5.58	762.1	-5.58	5.58	802.9
FEB 20 OCT 22	-5.18	5.18	500.2	-5.18	5.18	573.7	-5.18	5.18	639.3	-5.18	5.18	696.2	-5.18	5.18	744.4
FEB 7 NOV 5	-4.80	4.80	422.4	-4.80	4.80	499.6	-4.80	4.80	569.3	-4.80	4.80	630.7	-4.80	4.80	683.6
JAN 23 NOV 19	-4.47	4.47	360.2	-4.47	4.47	438.6	-4.47	4.47	510.0	-4.47	4.47	573.5	-4.47	4.47	628.8
JAN 10 DEC 3	-4.23	4.23	316.8	-4.23	4.23	395.0	-4.23	4.23	466.7	-4.23	4.23	530.8	-4.23	4.23	586.9
DEC 22	-4.08	4.08	291.7	-4.08	4.08	369.4	-4.08	4.08	440.7	-4.08	4.08	504.7	-4.08	4.08	561.0
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	246.071	.4682		262.996	.5004		277.162	.5273		288.521	.5489		297.218	.5655	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	17.0	0.0		13.0	0.0		9.3	0.0		6.0	0.0		3.0	0.0	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.51	6.51	947.9	-6.38	6.38	922.0	-6.27	6.27	895.3	-6.18	6.18	868.5	-6.09	6.09	842.1
JUN 1 JUL 12	-6.47	6.47	947.6	-6.36	6.36	924.6	-6.25	6.25	900.3	-6.16	6.16	875.7	-6.08	6.08	851.1
MAY 18 JUL 27	-6.41	6.41	945.7	-6.31	6.31	927.6	-6.22	6.22	907.6	-6.14	6.14	886.6	-6.07	6.07	865.3
MAY 3 AUG 10	-6.33	6.33	940.1	-6.25	6.25	928.9	-6.18	6.18	915.0	-6.11	6.11	899.4	-6.06	6.06	882.8
APR 19 AUG 25	-6.23	6.23	927.9	-6.17	6.17	925.1	-6.12	6.12	918.9	-6.08	6.08	910.0	-6.04	6.04	899.5
APR 4 SEP 9	-6.12	6.12	907.4	-6.09	6.09	914.2	-6.06	6.06	916.5	-6.04	6.04	915.4	-6.02	6.02	911.7
MAR 21 SEP 23	-6.00	6.00	876.9	-6.00	6.00	893.6	-6.00	6.00	905.0	-6.00	6.00	912.0	-6.00	6.00	915.8
MAR 7 OCT 8	-5.58	5.58	835.6	-5.58	5.58	861.3	-5.58	5.58	880.9	-5.58	5.58	895.6	-5.58	5.58	906.4
FEB 20 OCT 22	-5.18	5.18	784.3	-5.18	5.18	816.8	-5.18	5.18	842.9	-5.18	5.18	863.5	-5.18	5.18	879.8
FEB 7 NOV 5	-4.80	4.80	728.3	-4.80	4.80	765.4	-4.80	4.80	795.9	-4.80	4.80	820.7	-4.80	4.80	840.9
JAN 23 NOV 19	-4.47	4.47	676.0	-4.47	4.47	715.8	-4.47	4.47	748.8	-4.47	4.47	776.1	-4.47	4.47	798.7
JAN 10 DEC 3	-4.23	4.23	635.1	-4.23	4.23	676.0	-4.23	4.23	710.3	-4.23	4.23	738.8	-4.23	4.23	762.6
DEC 22	-4.08	4.08	609.4	-4.08	4.08	650.7	-4.08	4.08	685.4	-4.08	4.08	714.4	-4.08	4.08	738.7
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	303.532	.5775		307.834	.5857		310.488	.5907		311.847	.5933		312.216	.5940	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 48 N
ASPECT NNE - NNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	53.2		3.7	58.2		8.2	62.8		13.9	66.9		21.2	70.2		30.4
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.93	1013.9	-7.93	7.93	995.7	-7.93	7.93	969.2	-7.93	7.93	936.2	-7.93	7.93	898.7
JUN 1 JUL 12	-7.77	7.77	982.8	-7.77	7.77	959.9	-7.77	7.77	929.3	-7.77	7.77	892.7	-7.77	7.77	852.1
MAY 18 JUL 27	-7.53	7.53	929.8	-7.53	7.53	899.3	-7.53	7.53	862.0	-7.53	7.53	819.6	-7.53	7.53	774.1
MAY 3 AUG 10	-7.20	7.20	854.9	-7.20	7.20	814.7	-7.20	7.20	768.7	-7.20	7.20	718.9	-7.20	7.20	667.2
APR 19 AUG 25	-6.82	6.75	762.1	-6.82	6.66	711.4	-6.82	6.54	656.4	-6.82	6.38	599.2	-6.82	6.14	541.9
APR 4 SEP 9	-6.42	6.26	658.2	-6.42	6.06	598.0	-6.42	5.81	535.4	-6.42	5.48	472.9	-6.42	5.03	412.9
MAR 21 SEP 23	-6.00	5.76	548.4	-6.00	5.45	480.6	-6.00	5.07	413.0	-6.00	4.59	348.1	-6.00	3.97	288.6
MAR 7 OCT 8	-5.58	5.25	441.2	-5.58	4.84	368.6	-5.58	4.33	298.9	-5.58	3.70	234.9	-5.58	2.91	179.2
FEB 20 OCT 22	-5.18	4.76	343.9	-5.18	4.24	269.6	-5.18	3.60	200.9	-5.18	2.80	140.8	-5.18	1.81	92.1
FEB 7 NOV 5	-4.78	4.30	261.8	-4.76	3.67	188.5	-4.74	2.88	123.3	-4.70	1.87	69.7	-4.63	.57	30.7
JAN 23 NOV 19	-4.38	3.89	199.6	-4.25	3.15	129.2	-4.06	2.20	69.6	-3.73	.91	25.1	-2.85	-1.21	1.0
JAN 10 DEC 3	-4.07	3.58	158.4	-3.84	2.75	91.5	-3.48	1.62	38.1	-2.70	-.13	4.3	0.00	0.00	0.0
DEC 22	-3.87	3.38	135.6	-3.58	2.48	71.4	-3.08	1.22	22.8	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	207.365		.3945	187.428		.3566	168.005		.3196	150.317		.2860	135.361		.2575

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	72.8		41.8	74.4		54.9	75.1		68.6	75.0		81.5	74.3		92.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.93	858.6	-7.93	7.93	817.3	-7.93	7.93	776.2	-7.93	7.93	736.4	-7.93	7.93	698.6
JUN 1 JUL 12	-7.77	7.77	809.3	-7.77	7.77	766.0	-7.77	7.77	723.3	-7.77	7.77	682.1	-7.77	7.77	642.7
MAY 18 JUL 27	-7.53	7.53	727.3	-7.53	7.53	680.6	-7.53	7.53	635.3	-7.53	7.53	592.1	-7.53	7.53	550.7
MAY 3 AUG 10	-7.20	7.20	615.3	-7.20	7.20	564.6	-7.20	7.20	516.0	-7.20	7.20	470.3	*	*	427.6
APR 19 AUG 25	-6.82	5.79	486.3	-6.82	5.26	434.1	-6.82	4.53	387.0	-6.82	3.63	346.6	-6.82	2.70	313.2
APR 4 SEP 9	-6.42	4.45	357.4	-6.42	3.72	308.2	-6.42	2.88	266.9	-6.42	2.00	234.0	-6.42	1.19	208.4
MAR 21 SEP 23	-6.00	3.22	236.7	-6.00	2.34	193.8	-6.00	1.42	160.6	-6.00	.56	136.2	-6.00	-.17	118.5
MAR 7 OCT 8	-5.58	1.98	134.0	-5.58	.96	100.1	-5.58	-.03	76.6	-5.58	-.88	61.3	-5.58	-1.54	51.2
FEB 20 OCT 22	-5.18	.65	56.5	-5.18	-.58	33.8	-5.18	-1.68	21.1	-5.18	-2.50	14.6	-5.18	-2.93	11.1
FEB 7 NOV 5	-4.50	-1.07	7.8	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	122.499		.2331	111.298		.2118	101.679		.1935	93.371		.1776	86.166		.1639

* Double Sunrise - Sunset

(1)	-7.20	5.30
(2)	6.30	7.20

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 48 N
ASPECT SSE - SSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 42.7		ALPHA 3.0	THETA 37.4		ALPHA 5.4	THETA 32.3		ALPHA 7.5	THETA 27.4		ALPHA 9.2	THETA 22.8		ALPHA 10.7
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.77	7.38	1023.9	-7.66	6.93	1020.2	-7.56	6.56	1011.1	-7.48	6.25	996.9	-7.42	5.99	978.4
JUN 1 JUL 12	-7.65	7.26	1002.9	-7.56	6.84	1003.9	-7.48	6.49	999.1	-7.42	6.19	988.7	-7.37	5.94	973.9
MAY 18 JUL 27	-7.46	7.06	966.3	-7.40	6.68	975.0	-7.35	6.36	977.3	-7.31	6.08	973.6	-7.28	5.85	964.7
MAY 3 AUG 10	-7.19	6.80	913.0	-7.18	6.46	932.0	-7.17	6.18	944.1	-7.17	5.94	949.4	-7.16	5.74	948.8
APR 19 AUG 25	-6.82	6.48	844.2	-6.82	6.20	875.0	-6.82	5.97	898.3	-6.82	5.77	914.2	-6.82	5.60	923.5
APR 4 SEP 9	-6.42	6.15	763.5	-6.42	5.93	806.0	-6.42	5.74	840.7	-6.42	5.58	867.5	-6.42	5.45	886.9
MAR 21 SEP 23	-6.00	5.80	673.8	-6.00	5.64	726.9	-6.00	5.50	772.0	-6.00	5.39	808.9	-6.00	5.29	837.8
MAR 7 OCT 8	-5.58	5.45	581.8	-5.58	5.35	643.4	-5.58	5.26	697.1	-5.58	5.19	742.5	-5.58	5.13	779.7
FEB 20 OCT 22	-5.18	5.12	494.0	-5.18	5.07	561.6	-5.18	5.04	621.5	-5.18	5.00	673.3	-5.18	4.98	716.9
FEB 7 NOV 5	-4.80	4.80	416.0	-4.80	4.80	486.9	-4.80	4.80	550.7	-4.80	4.80	606.7	-4.80	4.80	654.7
JAN 23 NOV 19	-4.47	4.47	353.7	-4.47	4.47	425.8	-4.47	4.47	491.4	-4.47	4.47	549.4	-4.47	4.47	599.8
JAN 10 DEC 3	-4.23	4.23	310.4	-4.23	4.23	382.4	-4.23	4.23	448.2	-4.23	4.23	506.9	-4.23	4.23	558.1
DEC 22	-4.08	4.08	285.4	-4.08	4.08	356.9	-4.08	4.08	422.5	-4.08	4.08	481.1	-4.08	4.08	532.5
	YEAR 244.653		R.I. .4655	YEAR 260.410		R.I. .4955	YEAR 273.643		R.I. .5206	YEAR 284.274		R.I. .5409	YEAR 292.421		R.I. .5564

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 18.6		ALPHA 12.0	THETA 14.7		ALPHA 13.1	THETA 11.2		ALPHA 14.1	THETA 8.0		ALPHA 15.0	THETA 5.1		ALPHA 15.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.36	5.76	957.0	-7.31	5.56	933.6	-7.27	5.39	909.2	-7.23	5.23	884.7	-7.20	5.10	860.4
JUN 1 JUL 12	-7.32	5.72	955.5	-7.28	5.53	934.9	-7.25	5.36	913.0	-7.21	5.22	890.6	-7.19	5.09	868.2
MAY 18 JUL 27	-7.25	5.65	951.7	-7.23	5.48	935.8	-7.21	5.32	918.1	-7.19	5.19	899.4	-7.17	5.07	880.2
MAY 3 AUG 10	-7.16	5.56	943.3	-7.15	5.41	934.2	-7.15	5.27	922.4	-7.15	5.15	909.0	-7.15	5.04	894.4
APR 19 AUG 25	-6.82	5.45	927.0	-6.82	5.32	926.0	-6.82	5.21	921.5	-6.82	5.10	914.5	-6.82	5.01	905.7
APR 4 SEP 9	-6.42	5.33	899.7	-6.42	5.22	907.2	-6.42	5.13	910.4	-6.42	5.05	910.3	-6.42	4.98	907.7
MAR 21 SEP 23	-6.00	5.20	859.7	-6.00	5.13	875.4	-6.00	5.06	886.1	-6.00	5.00	892.8	-6.00	4.95	896.3
MAR 7 OCT 8	-5.58	5.07	809.3	-5.58	5.03	832.4	-5.58	4.99	849.9	-5.58	4.95	862.7	-5.58	4.92	871.9
FEB 20 OCT 22	-5.18	4.95	752.6	-5.18	4.93	781.8	-5.18	4.91	804.8	-5.18	4.90	822.8	-5.18	4.88	836.6
FEB 7 NOV 5	-4.80	4.80	695.0	-4.80	4.80	728.3	-4.80	4.80	755.5	-4.80	4.80	777.4	-4.80	4.80	795.1
JAN 23 NOV 19	-4.47	4.47	642.6	-4.47	4.47	676.5	-4.47	4.47	708.3	-4.47	4.47	732.7	-4.47	4.47	752.8
JAN 10 DEC 3	-4.23	4.23	602.0	-4.23	4.23	639.1	-4.23	4.23	670.1	-4.23	4.23	695.8	-4.23	4.23	717.1
DEC 22	-4.08	4.08	576.7	-4.08	4.08	614.2	-4.08	4.08	645.7	-4.08	4.08	671.9	-4.08	4.08	693.8
	YEAR 298.194		R.I. .5676	YEAR 302.355		R.I. .5753	YEAR 304.825		R.I. .5800	YEAR 306.073		R.I. .5823	YEAR 306.389		R.I. .5829

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 48 N
ASPECT NE - NW

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	51.9	6.5	55.2	14.1	58.0	22.5	60.0	31.6	61.2	41.0

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.81	1014.8	-7.93	7.65	997.8	-7.93	7.43	972.8	-7.93	7.14	941.9	-7.93	6.75	907.3
JUN 1 JUL 12	-7.77	7.62	985.0	-7.77	7.43	964.7	-7.77	7.17	937.1	-7.77	6.84	904.4	-7.77	6.41	868.7
MAY 18 JUL 27	-7.53	7.33	934.1	-7.53	7.09	906.6	-7.53	6.77	877.1	-7.53	6.38	841.5	-7.53	5.91	804.4
MAY 3 AUG 10	-7.20	6.95	862.0	-7.20	6.64	830.1	-7.20	6.26	793.7	-7.20	5.81	755.1	-7.20	5.30	716.6
APR 19 AUG 25	-6.82	6.51	772.5	-6.82	6.14	733.8	-6.82	5.70	692.7	-6.82	5.19	651.4	-6.82	4.63	612.2
APR 4 SEP 9	-6.42	6.04	671.6	-6.42	5.61	626.8	-6.42	5.10	582.0	-6.42	4.55	539.1	-6.42	3.95	500.2
MAR 21 SEP 23	-6.00	5.56	564.5	-6.00	5.06	515.0	-6.00	4.50	467.9	-6.00	3.89	424.9	-6.00	3.26	387.6
MAR 7 OCT 8	-5.58	5.08	459.2	-5.58	4.52	407.0	-5.58	3.89	359.3	-5.58	3.24	317.9	-5.58	2.58	283.4
FEB 20 OCT 22	-5.18	4.62	363.1	-5.18	3.99	310.2	-5.18	3.30	263.8	-5.18	2.59	225.2	-5.18	1.90	194.7
FEB 7 NOV 5	-4.80	4.18	281.4	-4.80	3.48	229.5	-4.80	2.73	185.8	-4.80	1.97	151.1	-4.80	1.23	125.1
JAN 23 NOV 19	-4.47	3.79	219.1	-4.47	3.04	169.2	-4.47	2.22	128.8	-4.47	1.40	98.3	-4.47	.62	76.7
JAN 10 DEC 3	-4.23	3.50	177.5	-4.23	2.69	129.8	-4.23	1.82	92.5	-4.23	.94	65.6	-4.23	.12	47.7
DEC 22	-4.08	3.32	154.2	-4.08	2.47	108.2	-4.08	1.56	73.0	-4.08	.64	48.5	-4.08	-.22	32.9

	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
	212.059	.4035	197.258	.3753	183.075	.3483	170.045	.3235	158.499	.3016

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	61.7	50.2	61.7	58.7	61.1	66.3	60.3	72.9	59.3	78.5

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	6.25	871.4	-7.93	5.67	836.2	-7.93	5.06	803.3	-7.93	4.46	773.6	-7.93	3.91	747.1
JUN 1 JUL 12	-7.77	5.89	832.4	-7.77	5.31	797.4	-7.77	4.72	765.2	-7.77	4.15	736.4	-7.77	3.62	710.8
MAY 18 JUL 27	-7.53	5.37	767.8	-7.53	4.79	733.4	-7.53	4.22	702.3	-7.53	3.68	674.9	-7.53	3.18	650.9
MAY 3 AUG 10	-7.20	4.74	680.0	-7.20	4.16	646.8	-7.20	3.61	617.4	-7.20	3.10	592.0	-7.20	2.64	570.1
APR 19 AUG 25	-6.82	4.06	576.4	-6.82	3.48	545.0	-6.82	2.95	518.0	-6.82	2.46	495.2	-6.82	2.03	475.8
APR 4 SEP 9	-6.42	3.36	466.2	-6.42	2.79	437.3	-6.42	2.27	413.3	-6.42	1.81	393.5	-6.42	1.40	377.0
MAR 21 SEP 23	-6.00	2.65	356.3	-6.00	2.09	330.8	-6.00	1.58	310.3	-6.00	1.14	293.9	-6.00	.77	280.5
MAR 7 OCT 8	-5.58	1.95	255.8	-5.58	1.38	234.3	-5.58	.89	217.6	-5.58	.48	204.6	-5.58	.13	194.4
FEB 20 OCT 22	-5.18	1.25	171.4	-5.18	.69	154.0	-5.18	.22	141.2	-5.18	-.18	131.6	-5.18	-.50	124.2
FEB 7 NOV 5	-4.80	.57	106.4	-4.80	.01	93.1	-4.80	-.45	83.8	-4.80	-.81	77.2	-4.80	-1.10	72.3
JAN 23 NOV 19	-4.47	-.06	62.2	-4.47	-.62	52.6	-4.47	-1.06	46.2	-4.47	-1.39	41.9	-4.47	-1.65	38.9
JAN 10 DEC 3	-4.23	-.58	36.4	-4.23	-1.14	29.5	-4.23	-1.56	25.2	-4.23	-1.86	22.5	-4.23	-2.09	20.6
DEC 22	-4.08	-.94	23.7	-4.08	-1.49	18.5	-4.08	-1.89	15.4	-4.08	-2.17	13.5	-4.08	-2.38	12.3

	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
	148.532	.2826	140.062	.2665	132.951	.2530	127.009	.2416	122.000	.2321

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 48 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	43.8	5.6		39.5	10.4		35.2	14.4		30.9	17.8		26.9	20.8	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.27	1023.9	-7.93	6.71	1022.1	-7.93	6.23	1016.4	-7.93	5.82	1006.9	-7.93	5.47	994.0
JUN 1 JUL 12	-7.77	7.14	1001.9	-7.77	6.60	1003.8	-7.77	6.14	1001.6	-7.77	5.74	995.4	-7.77	5.40	985.4
MAY 18 JUL 27	-7.53	6.94	963.4	-7.53	6.43	971.5	-7.53	5.99	975.1	-7.53	5.62	974.2	-7.53	5.30	969.2
MAY 3 AUG 10	-7.20	6.66	907.6	-7.20	6.20	923.8	-7.20	5.80	935.0	-7.20	5.45	941.2	-7.20	5.16	942.7
APR 19 AUG 25	-6.82	6.34	836.0	-6.82	5.92	861.1	-6.82	5.56	880.9	-6.82	5.25	895.1	-6.82	4.99	904.0
APR 4 SEP 9	-6.42	5.99	752.4	-6.42	5.62	786.4	-6.42	5.31	814.8	-6.42	5.04	837.0	-6.42	4.81	853.5
MAR 21 SEP 23	-6.00	5.63	660.2	-6.00	5.31	702.1	-6.00	5.04	738.0	-6.00	4.81	767.6	-6.00	4.61	791.0
MAR 7 OCT 8	-5.58	5.26	566.1	-5.58	5.00	614.2	-5.58	4.78	656.3	-5.58	4.59	691.8	-5.58	4.42	721.0
FEB 20 OCT 22	-5.18	4.92	476.9	-5.18	4.70	529.1	-5.18	4.52	575.4	-5.18	4.37	615.3	-5.18	4.24	648.6
FEB 7 NOV 5	-4.80	4.59	398.1	-4.80	4.42	452.4	-4.80	4.29	501.1	-4.80	4.17	543.5	-4.80	4.07	579.6
JAN 23 NOV 19	-4.47	4.32	335.5	-4.47	4.19	390.5	-4.47	4.09	440.0	-4.47	4.00	483.6	-4.47	3.93	521.1
JAN 10 DEC 3	-4.23	4.11	292.3	-4.23	4.02	347.0	-4.23	3.94	396.6	-4.23	3.88	440.4	-4.23	3.83	478.4
DEC 22	-4.08	3.98	267.4	-4.08	3.91	321.7	-4.08	3.85	371.0	-4.08	3.80	414.8	-4.08	3.76	452.8
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	240.567	.4577		252.899	.4812		263.349	.5010		271.780	.5171		278.235	.5294	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	23.2	23.3		19.7	25.5		16.5	27.4		13.6	29.1		11.0	30.6	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	5.16	978.5	-7.93	4.90	961.2	-7.93	4.66	942.8	-7.93	4.46	924.1	-7.93	4.28	905.2
JUN 1 JUL 12	-7.77	5.11	972.6	-7.77	4.85	957.7	-7.77	4.63	941.4	-7.77	4.43	924.5	-7.77	4.26	907.3
MAY 18 JUL 27	-7.53	5.02	960.8	-7.53	4.78	949.7	-7.53	4.57	937.0	-7.53	4.38	923.1	-7.53	4.22	908.6
MAY 3 AUG 10	-7.20	4.90	940.1	-7.20	4.68	934.4	-7.20	4.49	926.3	-7.20	4.32	916.7	-7.20	4.17	905.9
APR 19 AUG 25	-6.82	4.76	908.3	-6.82	4.56	908.7	-6.82	4.39	906.1	-6.82	4.24	901.2	-6.82	4.10	894.8
APR 4 SEP 9	-6.42	4.61	864.6	-6.42	4.43	871.3	-6.42	4.28	874.3	-6.42	4.15	874.6	-6.42	4.03	872.7
MAR 21 SEP 23	-6.00	4.45	808.6	-6.00	4.30	821.2	-6.00	4.17	829.7	-6.00	4.06	834.9	-6.00	3.96	837.5
MAR 7 OCT 8	-5.58	4.28	744.0	-5.58	4.16	761.8	-5.58	4.06	775.0	-5.58	3.97	784.5	-5.58	3.89	791.1
FEB 20 OCT 22	-5.18	4.13	675.8	-5.18	4.03	697.6	-5.18	3.95	714.5	-5.18	3.88	727.6	-5.18	3.82	737.4
FEB 7 NOV 5	-4.80	3.99	609.5	-4.80	3.92	634.0	-4.80	3.85	653.6	-4.80	3.80	669.2	-4.80	3.75	681.5
JAN 23 NOV 19	-4.47	3.87	552.5	-4.47	3.82	578.6	-4.47	3.77	599.9	-4.47	3.73	617.1	-4.47	3.70	631.0
JAN 10 DEC 3	-4.23	3.78	510.5	-4.23	3.74	537.4	-4.23	3.71	559.5	-4.23	3.68	577.6	-4.23	3.66	592.4
DEC 22	-4.08	3.73	485.2	-4.08	3.70	512.3	-4.08	3.68	534.8	-4.08	3.65	553.3	-4.08	3.64	568.6
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	282.886	.5382		285.994	.5441		287.831	.5476		288.664	.5492		288.731	.5493	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 48 N
ASPECT ENE - WNW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA 49.9		ALPHA 8.2	THETA 51.2		ALPHA 16.8	THETA 51.8		ALPHA 25.4	THETA 51.7		ALPHA 33.6	THETA 51.2		ALPHA 41.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.53	1017.2	-7.93	7.06	1005.0	-7.93	6.54	987.8	-7.93	5.99	967.4	-7.93	5.43	945.8
JUN 1 JUL 12	-7.77	7.36	989.3	-7.77	6.88	975.8	-7.77	6.36	957.8	-7.77	5.81	937.3	-7.77	5.26	915.8
MAY 18 JUL 27	-7.53	7.09	941.4	-7.53	6.60	925.8	-7.53	6.07	906.8	-7.53	5.52	885.9	-7.53	4.97	864.8
MAY 3 AUG 10	-7.20	6.74	873.3	-7.20	6.23	855.1	-7.20	5.69	834.8	-7.20	5.14	813.7	-7.20	4.60	793.1
APR 19 AUG 25	-6.82	6.34	788.0	-6.82	5.80	767.2	-6.82	5.25	745.7	-6.82	4.70	724.6	-6.82	4.18	704.9
APR 4 SEP 9	-6.42	5.90	691.3	-6.42	5.35	668.2	-6.42	4.79	645.9	-6.42	4.24	625.2	-6.42	3.72	606.7
MAR 21 SEP 23	-6.00	5.45	587.7	-6.00	4.88	562.8	-6.00	4.31	540.3	-6.00	3.76	520.5	-6.00	3.25	503.5
MAR 7 OCT 8	-5.58	5.00	484.9	-5.58	4.41	459.2	-5.58	3.83	437.1	-5.58	3.28	418.6	-5.58	2.78	403.5
FEB 20 OCT 22	-5.18	4.57	390.4	-5.18	3.96	364.6	-5.18	3.36	343.5	-5.18	2.81	326.6	-5.18	2.33	313.4
FEB 7 NOV 5	-4.80	4.16	309.2	-4.80	3.53	284.2	-4.80	2.93	264.4	-4.80	2.38	249.3	-4.80	1.90	238.0
JAN 23 NOV 19	-4.47	3.81	246.7	-4.47	3.16	222.7	-4.47	2.54	204.4	-4.47	2.00	191.0	-4.47	1.53	181.3
JAN 10 DEC 3	-4.23	3.54	204.5	-4.23	2.88	181.6	-4.23	2.25	164.6	-4.23	1.71	152.5	-4.23	1.24	144.0
DEC 22	-4.08	3.38	180.8	-4.08	2.70	158.6	-4.08	2.07	142.5	-4.08	1.53	131.2	-4.08	1.07	123.5
	YEAR 218.910		R.I. .4165	YEAR 211.229		R.I. .4019	YEAR 204.031		R.I. .3882	YEAR 197.488		R.I. .3757	YEAR 191.668		R.I. .3647

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 50.3		ALPHA 48.0	THETA 49.1		ALPHA 54.0	THETA 47.8		ALPHA 59.2	THETA 46.4		ALPHA 63.6	THETA 45.0		ALPHA 67.4
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	4.90	924.3	-7.93	4.41	903.6	-7.93	3.96	884.2	-7.93	3.57	866.2	-7.93	3.22	849.6
JUN 1 JUL 12	-7.77	4.73	894.7	-7.77	4.25	874.5	-7.77	3.81	855.7	-7.77	3.43	838.3	-7.77	3.09	822.3
MAY 18 JUL 27	-7.53	4.46	844.3	-7.53	3.99	825.1	-7.53	3.57	807.3	-7.53	3.20	791.0	-7.53	2.87	776.0
MAY 3 AUG 10	-7.20	4.10	773.7	-7.20	3.65	755.8	-7.20	3.25	739.4	-7.20	2.90	724.6	-7.20	2.59	711.0
APR 19 AUG 25	-6.82	3.69	686.9	-6.82	3.26	670.6	-6.82	2.87	656.1	-6.82	2.54	643.0	-6.82	2.25	631.2
APR 4 SEP 9	-6.42	3.25	590.3	-6.42	2.84	576.0	-6.42	2.47	563.4	-6.42	2.16	552.3	-6.42	1.88	542.3
MAR 21 SEP 23	-6.00	2.80	489.1	-6.00	2.40	476.9	-6.00	2.06	466.4	-6.00	1.76	457.3	-6.00	1.51	449.3
MAR 7 OCT 8	-5.58	2.34	391.1	-5.58	1.96	381.0	-5.58	1.64	372.6	-5.58	1.37	365.4	-5.58	1.13	359.1
FEB 20 OCT 22	-5.18	1.90	303.1	-5.18	1.54	294.9	-5.18	1.24	288.3	-5.18	.98	282.9	-5.18	.77	278.2
FEB 7 NOV 5	-4.80	1.49	229.5	-4.80	1.15	223.1	-4.80	.86	218.0	-4.80	.63	214.0	-4.80	.43	210.6
JAN 23 NOV 19	-4.47	1.13	174.3	-4.47	.81	169.2	-4.47	.54	165.4	-4.47	.32	162.3	-4.47	.14	159.9
JAN 10 DEC 3	-4.23	.86	138.1	-4.23	.55	133.9	-4.23	.30	130.9	-4.23	.09	128.5	-4.23	-.08	126.6
DEC 22	-4.08	.70	118.2	-4.08	.39	114.5	-4.08	.15	111.9	-4.08	-.05	109.9	-4.08	-.21	108.3
	YEAR 186.543		R.I. .3549	YEAR 182.035		R.I. .3463	YEAR 178.061		R.I. .3388	YEAR 174.540		R.I. .3321	YEAR 171.371		R.I. .3260

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 48 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	45.6	7.6		42.7	14.3		39.7	20.2		36.5	25.3		33.4	29.7	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.25	1022.7	-7.93	6.63	1020.4	-7.93	6.06	1015.5	-7.93	5.57	1007.9	-7.93	5.13	998.1
JUN 1 JUL 12	-7.77	7.12	999.0	-7.77	6.51	998.9	-7.77	5.96	996.2	-7.77	5.47	990.8	-7.77	5.05	983.0
MAY 18 JUL 27	-7.53	6.89	957.8	-7.53	6.31	961.5	-7.53	5.78	962.4	-7.53	5.32	960.5	-7.53	4.91	956.0
MAY 3 AUG 10	-7.20	6.60	898.3	-7.20	6.04	906.9	-7.20	5.55	912.7	-7.20	5.11	915.4	-7.20	4.73	915.1
APR 19 AUG 25	-6.82	6.25	822.6	-6.82	5.73	836.6	-6.82	5.27	847.8	-6.82	4.86	855.6	-6.82	4.51	860.2
APR 4 SEP 9	-6.42	5.88	735.1	-6.42	5.40	754.4	-6.42	4.97	770.8	-6.42	4.59	783.8	-6.42	4.27	793.2
MAR 21 SEP 23	-6.00	5.50	639.4	-6.00	5.05	663.3	-6.00	4.66	684.4	-6.00	4.32	701.9	-6.00	4.02	715.7
MAR 7 OCT 8	-5.58	5.11	542.6	-5.58	4.70	570.1	-5.58	4.34	594.8	-5.58	4.04	615.9	-5.58	3.77	633.2
FEB 20 OCT 22	-5.18	4.74	451.6	-5.18	4.36	481.5	-5.18	4.04	508.6	-5.18	3.77	532.1	-5.18	3.54	551.9
FEB 7 NOV 5	-4.80	4.40	371.9	-4.80	4.05	402.9	-4.80	3.76	431.2	-4.80	3.52	456.0	-4.80	3.32	477.2
JAN 23 NOV 19	-4.47	4.10	309.1	-4.47	3.79	340.3	-4.47	3.53	368.9	-4.47	3.31	394.2	-4.47	3.13	415.9
JAN 10 DEC 3	-4.23	3.88	266.0	-4.23	3.59	296.9	-4.23	3.35	325.4	-4.23	3.16	350.6	-4.23	3.00	372.4
DEC 22	-4.08	3.74	241.4	-4.08	3.47	272.0	-4.08	3.25	300.1	-4.08	3.06	325.1	-4.08	2.91	346.8
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	234.321	.4458		241.221	.4589		247.126	.4702		251.867	.4792		255.409	.4859	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	30.4	33.4		27.5	36.7		24.9	39.5		22.4	41.9		20.1	44.1	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	4.76	986.5	-7.93	4.43	973.4	-7.93	4.14	959.5	-7.93	3.89	945.2	-7.93	3.67	930.8
JUN 1 JUL 12	-7.77	4.68	973.2	-7.77	4.36	961.7	-7.77	4.08	949.3	-7.77	3.84	936.3	-7.77	3.63	923.1
MAY 18 JUL 27	-7.53	4.56	949.1	-7.53	4.26	940.4	-7.53	3.99	930.4	-7.53	3.76	919.5	-7.53	3.55	908.2
MAY 3 AUG 10	-7.20	4.40	912.2	-7.20	4.11	907.1	-7.20	3.86	900.3	-7.20	3.64	892.4	-7.20	3.45	883.7
APR 19 AUG 25	-6.82	4.20	861.8	-6.82	3.94	860.8	-6.82	3.71	857.7	-6.82	3.51	853.1	-6.82	3.33	847.4
APR 4 SEP 9	-6.42	3.99	799.3	-6.42	3.75	802.4	-6.42	3.54	803.2	-6.42	3.36	802.0	-6.42	3.20	799.4
MAR 21 SEP 23	-6.00	3.77	725.4	-6.00	3.55	732.8	-6.00	3.37	737.1	-6.00	3.20	739.2	-6.00	3.06	739.7
MAR 7 OCT 8	-5.58	3.55	646.6	-5.58	3.36	657.0	-5.58	3.19	664.3	-5.58	3.05	669.2	-5.58	2.92	672.2
FEB 20 OCT 22	-5.18	3.34	567.9	-5.18	3.17	580.4	-5.18	3.02	590.0	-5.18	2.90	597.1	-5.18	2.79	602.2
FEB 7 NOV 5	-4.80	3.14	494.7	-4.80	3.00	508.8	-4.80	2.87	519.9	-4.80	2.76	528.4	-4.80	2.67	535.0
JAN 23 NOV 19	-4.47	2.98	434.1	-4.47	2.85	449.0	-4.47	2.74	460.9	-4.47	2.65	470.4	-4.47	2.57	477.8
JAN 10 DEC 3	-4.23	2.86	390.7	-4.23	2.75	405.9	-4.23	2.65	418.2	-4.23	2.57	428.1	-4.23	2.49	436.0
DEC 22	-4.08	2.79	365.2	-4.08	2.68	380.4	-4.08	2.59	392.8	-4.08	2.52	402.9	-4.08	2.45	411.0
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	257.817	.4905		259.235	.4932		259.831	.4944		259.778	.4943		259.228	.4932	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 48 N
ASPECT E - W

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	47.7	8.5		46.8	16.7		45.4	24.1		43.6	30.9		41.7	36.8	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	7.33	1020.2	-7.93	6.73	1014.0	-7.93	6.13	1005.0	-7.93	5.57	993.9	-7.93	5.07	981.5
JUN 1 JUL 12	-7.77	7.19	994.4	-7.77	6.58	988.8	-7.77	6.00	980.6	-7.77	5.45	970.5	-7.77	4.95	959.1
MAY 18 JUL 27	-7.53	6.94	949.9	-7.53	6.35	945.2	-7.53	5.78	938.4	-7.53	5.24	929.9	-7.53	4.76	920.2
MAY 3 AUG 10	-7.20	6.62	886.2	-7.20	6.04	882.8	-7.20	5.48	877.7	-7.20	4.97	871.4	-7.20	4.51	863.9
APR 19 AUG 25	-6.82	6.25	805.8	-6.82	5.68	803.8	-6.82	5.14	800.8	-6.82	4.65	796.9	-6.82	4.21	792.0
APR 4 SEP 9	-6.42	5.85	713.7	-6.42	5.29	713.2	-6.42	4.77	712.3	-6.42	4.30	710.8	-6.42	3.88	708.6
MAR 21 SEP 23	-6.00	5.43	614.0	-6.00	4.89	614.9	-6.00	4.39	616.0	-6.00	3.94	616.8	-6.00	3.55	617.0
MAR 7 OCT 8	-5.58	5.02	514.2	-5.58	4.49	516.3	-5.58	4.01	519.0	-5.58	3.58	521.8	-5.58	3.21	524.1
FEB 20 OCT 22	-5.18	4.62	421.4	-5.18	4.10	424.4	-5.18	3.64	428.3	-5.18	3.24	432.6	-5.18	2.89	436.4
FEB 7 NOV 5	-4.80	4.24	340.9	-4.80	3.74	344.4	-4.80	3.30	349.3	-4.80	2.91	354.4	-4.80	2.59	359.3
JAN 23 NOV 19	-4.47	3.92	278.1	-4.47	3.43	282.0	-4.47	3.00	287.3	-4.47	2.64	293.0	-4.47	2.34	298.4
JAN 10 DEC 3	-4.23	3.68	235.4	-4.23	3.20	239.5	-4.23	2.78	245.0	-4.23	2.43	250.8	-4.23	2.15	256.5
DEC 22	-4.08	3.53	211.2	-4.08	3.05	215.3	-4.08	2.65	220.8	-4.08	2.31	226.7	-4.08	2.03	232.4
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	226.741	.4314		226.695	.4313		226.538	.4310		226.185	.4303		225.582	.4292	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA		THETA	ALPHA	
	39.6	41.9		37.5	46.3		35.5	50.1		33.5	53.4		31.7	56.2	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.93	4.61	968.3	-7.93	4.21	954.7	-7.93	3.86	940.9	-7.93	3.56	927.4	-7.93	3.29	914.1
JUN 1 JUL 12	-7.77	4.51	946.9	-7.77	4.12	934.3	-7.77	3.77	921.4	-7.77	3.48	908.8	-7.77	3.21	896.2
MAY 18 JUL 27	-7.53	4.33	909.7	-7.53	3.95	898.7	-7.53	3.63	887.4	-7.53	3.34	876.1	-7.53	3.09	864.9
MAY 3 AUG 10	-7.20	4.10	855.7	-7.20	3.74	846.9	-7.20	3.42	837.6	-7.20	3.15	828.3	-7.20	2.91	818.8
APR 19 AUG 25	-6.82	3.82	786.4	-6.82	3.48	780.1	-6.82	3.19	773.2	-6.82	2.93	766.0	-6.82	2.71	758.6
APR 4 SEP 9	-6.42	3.52	705.6	-6.42	3.20	701.9	-6.42	2.93	697.4	-6.42	2.69	692.6	-6.42	2.49	687.3
MAR 21 SEP 23	-6.00	3.21	616.5	-6.00	2.91	615.1	-6.00	2.66	613.0	-6.00	2.44	610.3	-6.00	2.25	607.1
MAR 7 OCT 8	-5.58	2.90	525.6	-5.58	2.62	526.3	-5.58	2.39	526.2	-5.58	2.19	525.4	-5.58	2.02	524.0
FEB 20 OCT 22	-5.18	2.60	439.5	-5.18	2.35	441.8	-5.18	2.13	443.2	-5.18	1.95	443.9	-5.18	1.80	443.9
FEB 7 NOV 5	-4.80	2.32	363.5	-4.80	2.09	366.8	-4.80	1.90	369.3	-4.80	1.73	371.0	-4.80	1.59	372.0
JAN 23 NOV 19	-4.47	2.08	303.1	-4.47	1.87	307.1	-4.47	1.70	310.2	-4.47	1.55	312.5	-4.47	1.42	314.1
JAN 10 DEC 3	-4.23	1.91	261.5	-4.23	1.71	265.7	-4.23	1.55	269.1	-4.23	1.41	271.7	-4.23	1.29	273.7
DEC 22	-4.08	1.80	237.5	-4.08	1.61	241.8	-4.08	1.46	245.4	-4.08	1.33	248.1	-4.08	1.21	250.3
	YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.		YEAR	R.I.	
	224.704	.4275		223.569	.4254		222.217	.4228		220.700	.4199		219.059	.4168	

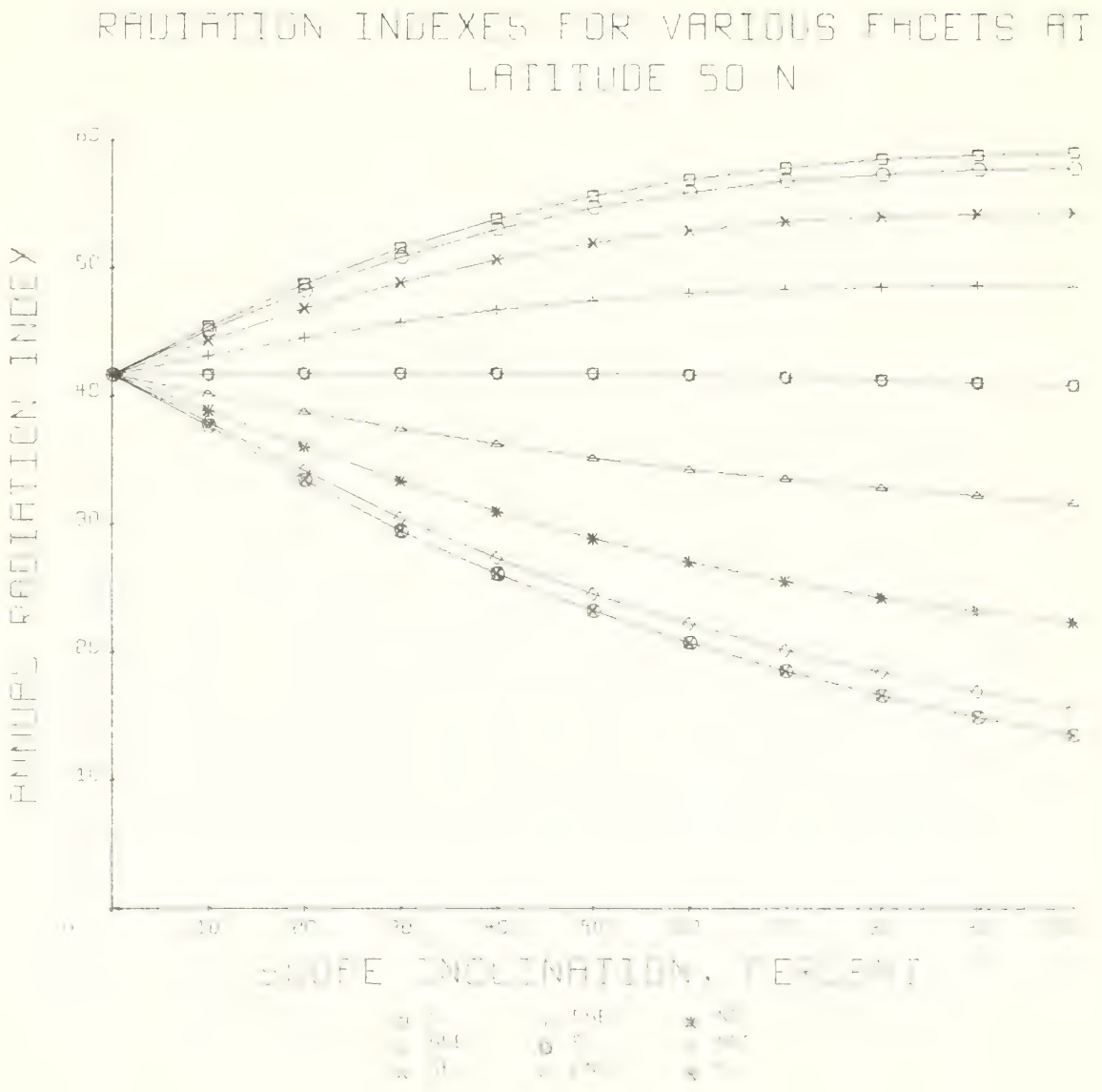
NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

HORIZONTAL SURFACE

LATITUDE 50 N

		SR	SS	LY
JUN 22		-8.08	8.08	1020.9
JUN 1	JUL 12	-7.92	7.92	992.9
MAY 18	JUL 27	-7.65	7.65	944.8
MAY 3	AUG 10	-7.29	7.29	876.4
APR 19	AUG 25	-6.89	6.89	790.8
APR 4	SEP 9	-6.45	6.45	693.6
MAR 21	SEP 23	-6.00	6.00	589.5
MAR 7	OCT 8	-5.55	5.55	486.3
FEB 20	OCT 24	-5.11	5.11	391.3
FEB 7	NOV 5	-4.71	4.71	309.8
JAN 23	NOV 19	-4.35	4.35	246.9
JAN 10	DEC 3	-4.08	4.08	204.6
DEC 12		-3.92	3.92	180.7

YEAR	R.I.
219.589	.4178



LATITUDE 50 N
ASPECT N -

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	55.7		0.0	61.3		0.0	66.7		0.0	71.8		0.0	76.6		0.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	8.08	1010.7	-8.08	8.08	990.9	-8.08	8.08	962.9	-8.08	8.08	928.6	-8.08	8.08	889.9
JUN 1 JUL 12	-7.92	7.92	976.9	-7.92	7.92	951.8	-7.92	7.92	919.2	-7.92	7.92	880.7	-7.92	7.92	838.5
MAY 18 JUL 27	-7.65	7.65	919.6	-7.65	7.65	886.1	-7.65	7.65	845.8	-7.65	7.65	800.8	-7.65	7.65	753.1
MAY 3 AUG 10	-7.29	7.29	839.3	-7.29	7.29	794.9	-7.29	7.29	745.0	-7.29	7.29	691.7	-7.29	7.29	637.0
APR 19 AUG 25	-6.89	6.89	740.7	-6.89	6.89	684.6	-6.89	6.89	624.4	-6.89	6.89	562.3	-6.89	6.89	500.3
APR 4 SEP 9	-6.45	6.45	631.2	-6.45	6.45	564.0	-6.45	6.45	494.3	-6.45	6.45	424.2	-6.45	6.45	355.7
MAR 21 SEP 23	-6.00	6.00	516.6	-6.00	6.00	440.2	-6.00	6.00	362.8	-6.00	6.00	286.4	-6.00	6.00	213.1
MAR 7 OCT 8	-5.45	5.45	405.9	-5.31	5.31	323.8	-5.12	5.12	242.6	-4.84	4.84	165.0	-4.37	4.37	93.6
FEB 20 OCT 22	-4.90	4.90	307.0	-4.62	4.62	223.5	-4.23	4.23	144.2	-3.61	3.61	73.2	-2.41	2.41	17.1
FEB 7 NOV 5	-4.39	4.39	225.0	-3.96	3.96	144.0	-3.31	3.31	71.8	-2.13	2.13	15.8	0.00	0.00	0.0
JAN 23 NOV 19	-3.94	3.94	163.9	-3.34	3.34	88.1	-2.36	2.36	26.7	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	-3.58	3.58	124.2	-2.83	2.83	54.2	-1.37	1.37	5.2	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	-3.36	3.36	102.5	-2.49	2.49	37.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	198.233		.3772	176.354		.3355	155.544		.2959	137.964		.2625	122.751		.2335

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	81.0		0.0	85.0		0.0	88.7		0.0	88.0		180.0	85.0		180.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	8.08	848.7	-8.08	8.08	806.5	-8.08	8.08	764.8	-8.08	8.08	724.0	-8.08	8.08	685.2
JUN 1 JUL 12	-7.92	7.92	794.3	-7.92	7.92	749.8	-7.92	7.92	706.1	-7.92	7.92	663.8	-7.92	7.92	623.7
MAY 18 JUL 27	-7.65	7.65	704.3	-7.65	7.65	656.0	-7.65	7.65	609.3	-7.65	7.65	564.6	-7.65	7.65	522.6
MAY 3 AUG 10	-7.29	7.29	582.5	-7.29	7.29	529.5	-7.29	7.29	479.2	-7.29	7.29	431.6	-7.29	7.29	387.5
APR 19 AUG 25	-6.89	6.89	439.9	-6.89	6.89	382.3	-6.89	6.89	328.4	-6.89	6.89	278.1	-6.89	6.89	231.9
APR 4 SEP 9	-6.45	6.45	290.2	-6.45	6.45	228.7	-6.45	6.45	171.9	-6.45	6.45	119.5	-6.45	6.45	71.9
MAR 21 SEP 23	-6.00	6.00	144.0	-6.00	6.00	79.9	-6.00	6.00	21.5	0.00	0.00	0.0	0.00	0.00	0.0
MAR 7 OCT 8	-3.44	3.44	32.5	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
FEB 20 OCT 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
FEB 7 NOV 5	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	109.483		.2083	97.879		.1862	87.775		.1670	79.174		.1506	71.751		.1365

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 50 N
ASPECT S -

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	44.3	0.0	38.7	0.0	33.3	0.0	28.2	0.0	23.4	0.0

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-7.67	7.67	1024.0	-7.36	7.36	1021.6	-7.11	7.11	1013.4	-6.90	6.90	999.5	-6.72	6.72	981.1
JUN 1 JUL 12	-7.54	7.54	1001.5	-7.26	7.26	1004.2	-7.02	7.02	1000.5	-6.83	6.83	990.8	-6.67	6.67	976.1
MAY 18 JUL 27	-7.33	7.33	962.5	-7.09	7.09	973.5	-6.89	6.89	977.4	-6.72	6.72	974.6	-6.58	6.58	966.1
MAY 3 AUG 10	-7.05	7.05	905.9	-6.86	6.86	928.0	-6.70	6.70	942.2	-6.57	6.57	949.0	-6.46	6.46	949.2
APR 19 AUG 25	-6.72	6.72	833.5	-6.59	6.59	868.2	-6.49	6.49	894.4	-6.40	6.40	912.5	-6.32	6.32	923.1
APR 4 SEP 9	-6.37	6.37	749.3	-6.30	6.30	796.8	-6.25	6.25	835.5	-6.20	6.20	865.5	-6.16	6.16	887.5
MAR 21 SEP 23	-6.00	6.00	656.5	-6.00	6.00	715.9	-6.00	6.00	766.5	-6.00	6.00	808.2	-6.00	6.00	841.5
MAR 7 OCT 8	-5.55	5.55	562.1	-5.55	5.55	630.8	-5.55	5.55	691.3	-5.55	5.55	742.9	-5.55	5.55	785.9
FEB 20 OCT 22	-5.11	5.11	472.4	-5.11	5.11	547.3	-5.11	5.11	614.4	-5.11	5.11	673.0	-5.11	5.11	722.9
FEB 7 NOV 5	-4.71	4.71	393.1	-4.71	4.71	470.9	-4.71	4.71	541.5	-4.71	4.71	604.0	-4.71	4.71	658.0
JAN 23 NOV 19	-4.35	4.35	330.1	-4.35	4.35	408.4	-4.35	4.35	480.0	-4.35	4.35	543.9	-4.35	4.35	599.8
JAN 10 DEC 3	-4.08	4.08	286.4	-4.08	4.08	363.9	-4.08	4.08	435.1	-4.08	4.08	499.0	-4.08	4.08	555.2
DEC 22	-3.92	3.92	261.3	-3.92	3.92	337.8	-3.92	3.92	408.3	-3.92	3.92	471.7	-3.92	3.92	527.7

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
239.370	.4554	256.847	.4887	271.625	.5168	283.622	.5396	292.960	.5574

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	19.0	0.0	15.0	0.0	11.3	0.0	8.0	0.0	5.0	0.0

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-6.58	6.58	959.3	-6.45	6.45	935.3	-6.33	6.33	910.3	-6.23	6.23	884.9	-6.15	6.15	859.8
JUN 1 JUL 12	-6.53	6.53	957.6	-6.41	6.41	936.5	-6.31	6.31	913.9	-6.22	6.22	890.8	-6.13	6.13	867.6
MAY 18 JUL 27	-6.46	6.46	953.2	-6.36	6.36	937.1	-6.27	6.27	918.9	-6.19	6.19	899.6	-6.12	6.12	879.7
MAY 3 AUG 10	-6.37	6.37	944.1	-6.29	6.29	935.0	-6.21	6.21	923.0	-6.15	6.15	909.1	-6.09	6.09	894.1
APR 19 AUG 25	-6.25	6.25	927.5	-6.20	6.20	927.0	-6.15	6.15	922.7	-6.10	6.10	915.7	-6.06	6.06	906.8
APR 4 SEP 9	-6.13	6.13	902.4	-6.10	6.10	911.4	-6.08	6.08	915.7	-6.05	6.05	916.4	-6.03	6.03	914.4
MAR 21 SEP 23	-6.00	6.00	867.0	-6.00	6.00	885.9	-6.00	6.00	899.2	-6.00	6.00	908.1	-6.00	6.00	913.6
MAR 7 OCT 8	-5.55	5.55	820.8	-5.55	5.55	848.5	-5.55	5.55	870.0	-5.55	5.55	886.4	-5.55	5.55	898.7
FEB 20 OCT 22	-5.11	5.11	764.5	-5.11	5.11	798.8	-5.11	5.11	826.5	-5.11	5.11	848.6	-5.11	5.11	866.3
FEB 7 NOV 5	-4.71	4.71	703.9	-4.71	4.71	742.3	-4.71	4.71	774.1	-4.71	4.71	800.1	-4.71	4.71	821.4
JAN 23 NOV 19	-4.35	4.35	647.6	-4.35	4.35	686.2	-4.35	4.35	722.1	-4.35	4.35	750.3	-4.35	4.35	773.7
JAN 10 DEC 3	-4.08	4.08	603.6	-4.08	4.08	644.9	-4.08	4.08	679.7	-4.08	4.08	708.8	-4.08	4.08	733.2
DEC 22	-3.92	3.92	576.1	-3.92	3.92	617.5	-3.92	3.92	652.4	-3.92	3.92	681.8	-3.92	3.92	706.5

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
299.897	.5706	304.792	.5799	308.000	.5860	309.870	.5896	310.712	.5914

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

SLOPE

	10 PCT			30 PCT			50 PCT			70 PCT			90 PCT		
	THETA 25.2	ALPHA 3.6		THETA 82.1	ALPHA 9.7		THETA 67.7	ALPHA 3.7		THETA 88.1	ALPHA 3.0		THETA 71.9	ALPHA 10.5	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 12	-6.08	8.08	1251.1	-8.08	8.08	1174.7	-8.08	8.08	1067.1	-8.08	8.08	910.1	-8.08	8.08	675.1
JUN 13 JUL 12	-7.92	7.92	1071.1	-7.92	7.92	981.1	-7.92	7.92	871.6	-7.92	7.92	801.0	-7.92	7.92	644.1
MAY 18 JUL 27	-7.65	7.65	892.1	-7.65	7.65	808.1	-7.65	7.65	698.2	-7.65	7.65	601.1	-7.65	7.65	450.1
MAY 3 AUG 10	-7.29	7.29	894.0	-7.29	7.29	799.6	-7.29	7.29	752.2	-7.29	7.29	651.0	-7.29	7.29	548.1
APR 19 AUG 25	-6.89	6.82	749.1	-6.89	6.13	691.7	-6.89	6.81	665.0	-6.89	6.84	576.5	-6.89	6.18	517.8
APR 4 SEP 9	-6.45	6.27	635.4	-6.45	6.08	572.9	-6.45	5.81	509.4	-6.45	5.95	448.3	-6.45	4.94	385.7
MAR 21 SEP 23	-6.00	5.76	532.3	-6.00	5.42	453.3	-6.00	4.80	389.7	-6.00	4.70	318.6	-6.00	3.77	260.6
MAR 7 OCT 8	-5.55	5.00	411.3	-5.55	4.76	337.5	-5.55	4.20	288.6	-5.55	3.49	230.4	-5.55	2.59	192.8
FEB 22 OCT 22	-5.11	4.97	314.8	-5.11	4.11	248.1	-5.11	3.40	172.4	-5.11	2.48	114.4	-5.11	1.32	59.5
FEB 7 NOV 5	-4.68	4.17	232.7	-4.64	3.48	160.3	-4.68	2.59	87.1	-4.68	1.42	47.3	-4.31	-.16	14.6
JAN 23 NOV 19	-4.13	3.72	170.3	-4.00	2.90	102.7	-3.79	1.80	47.1	-3.25	.18	7.6	0.00	0.00	0.0
JAN 10 DEC 3	-1.89	3.38	130.9	-3.60	2.44	67.2	-3.08	1.09	18.7	0.00	0.0	0.0	0.00	0.00	0.0
DEC 22	-1.67	3.16	108.9	-3.29	2.13	48.8	-1.52	.55	1.7	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 188.932	R.I. .3804		YEAR 179.935	R.I. .3623		YEAR 160.786	R.I. .3237		YEAR 138.047	R.I. .2780		YEAR 120.764	R.I. .2432	

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA 74.6	ALPHA 46.5		THETA 75.5	ALPHA 61.2		THETA 75.7	ALPHA 75.0		THETA 75.2	ALPHA 85.6		THETA 74.1	ALPHA 90.6	
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 12	-8.08	8.08	850.7	-8.08	8.08	808.7	-8.08	8.08	767.1	-8.08	8.08	726.5	-8.08	8.08	688.0
JUN 13 JUL 12	-7.92	7.92	796.7	-7.92	7.92	754.6	-7.92	7.92	711..	-7.92	7.92	669..	-7.92	7.92	629..
MAY 18 JUL 27	-7.65	7.65	712.3	-7.65	7.65	664.9	-7.65	7.65	618.9	-7.65	7.65	575.2	-7.65	7.65	533.9
MAY 3 AUG 10	-7.29	7.29	595.3	-7.29	7.29	543.8	-7.29	7.29	494.7	-7.29	7.29	448.5	*	*	..8
APR 19 AUG 25	-6.89	6.78	461.4	-6.89	6.13	408.6	-6.89	6.22	362.3	-6.89	6.18	323.6	-6.89	2.19	292.8
APR 4 SEP 9	-6.45	6.27	330.4	-6.45	3.41	282.4	-6.45	2.46	243.4	-6.45	1.52	213.3	-6.45	.71	190.8
MAR 21 SEP 23	-6.00	2.90	210.3	-6.00	1.92	170.1	-6.00	.93	140.4	-6.00	.07	119.4	-6.00	-.64	104.6
MAR 7 OCT 8	-5.55	1.54	110.8	-5.55	.42	81.6	-5.55	-.59	61.7	-5.55	-1.39	49.7	-5.55	-1.99	42.2
FEB 22 OCT 22	-5.11	.03	38.9	-5.11	-1.29	21.6	-5.11	-2.35	13.1	-5.11	-3.05	7.2	-5.11	-3.46	3.3
FEB 7 NOV 5	-4.68	-.52	.3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 23 NOV 19	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
JAN 10 DEC 3	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
DEC 22	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.0
	YEAR 137.327	R.I. .2252		YEAR 108.624	R.I. .2029		YEAR 97.354	R.I. .1852		YEAR 89.397	R.I. .1701		YEAR 82.523	R.I. .1570	

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

* Double Sunrise - Sunset

LATITUDE 50 N
ASPECT SSE - SSW

SLOPE

		10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
		THETA 44.7		ALPHA 3.1	THETA 39.4		ALPHA 5.6	THETA 34.3		ALPHA 7.6	THETA 29.4		ALPHA 9.4	THETA 24.8		ALPHA 10.9
		SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22		-7.90	7.49	1023.9	-7.77	7.02	1024.3	-7.60	6.64	1015.3	-7.57	6.32	1003.3	-7.50	6.05	987.0
JUN 1	JUL 12	-7.77	7.36	1001.1	-7.66	6.92	1004.2	-7.57	6.55	1001.7	-7.50	6.25	993.0	-7.44	5.99	980.3
MAY 18	JUL 27	-7.56	7.15	961.5	-7.49	6.74	972.5	-7.43	6.41	977.2	-7.39	6.13	975.8	-7.35	5.90	969.1
MAY 3	AUG 15	-7.27	6.86	904.1	-7.25	6.51	925.6	-7.24	6.22	940.2	-7.23	5.96	948.0	-7.22	5.77	949.7
APR 19	AUG 25	-6.89	6.53	830.8	-6.89	6.24	864.2	-6.89	5.99	890.1	-6.89	5.79	908.6	-6.89	5.62	920.2
APR 4	SEP 9	-6.45	6.17	745.1	-6.45	5.94	790.6	-6.45	5.75	827.6	-6.45	5.59	857.1	-6.45	5.45	876.5
MAR 21	SEP 23	-6.00	5.80	651.7	-6.00	5.63	707.1	-6.00	5.49	754.5	-6.00	5.37	793.7	-6.00	5.28	825.0
MAR 7	OCT 8	-5.55	5.42	556.5	-5.55	5.32	619.8	-5.55	5.23	675.4	-5.55	5.16	722.8	-5.55	5.10	762.1
FEB 20	OCT 22	-5.11	5.06	466.1	-5.11	5.02	535.0	-5.11	4.99	596.4	-5.11	4.96	649.7	-5.11	4.93	695.0
FEB 7	NOV 5	-4.71	4.71	386.6	-4.71	4.71	456.2	-4.71	4.71	522.5	-4.71	4.71	579.5	-4.71	4.71	629.0
JAN 23	NOV 19	-4.35	4.35	323.0	-4.35	4.35	395.7	-4.35	4.35	461.4	-4.35	4.35	519.9	-4.35	4.35	570.9
JAN 10	DEC 3	-4.08	4.08	280.1	-4.08	4.08	351.5	-4.08	4.08	416.9	-4.08	4.08	475.3	-4.08	4.08	526.1
DEC 22		-3.92	3.92	255.1	-3.92	3.92	325.6	-3.92	3.92	390.4	-3.92	3.92	448.6	-3.92	3.92	499.8
		YEAR 237.921		R.I. .4527	YEAR 254.203		R.I. .4836	YEAR 268.020		R.I. .5099	YEAR 279.267		R.I. .5313	YEAR 288.025		R.I. .5480

SLOPE

		60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
		THETA 20.6		ALPHA 12.1	THETA 16.7		ALPHA 13.6	THETA 13.1		ALPHA 14.7	THETA 9.9		ALPHA 15.6	THETA 7.6		ALPHA 15.8
		SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22		-7.44	5.68	967.4	-7.38	5.62	945.1	-7.34	5.44	922.9	-7.27	5.29	899.1	-7.20	5.15	876.6
JUN 1	JUL 12	-7.39	5.79	964.5	-7.35	5.58	945.1	-7.31	5.41	925.4	-7.27	5.24	904.7	-7.22	5.13	883.4
MAY 18	JUL 27	-7.31	5.69	956.3	-7.29	5.52	944.3	-7.26	5.37	928.2	-7.24	5.21	911.0	-7.22	5.11	893.1
MAY 3	AUG 10	-7.23	5.59	946.4	-7.20	5.46	934.2	-7.20	5.30	925.3	-7.19	5.18	917.9	-7.19	5.08	904.1
APR 19	AUG 25	-6.89	5.47	926.1	-6.89	5.34	921.1	-6.89	5.22	914.1	-6.89	5.10	905.4	-6.89	5.04	894.4
APR 4	SEP 9	-6.45	5.33	894.1	-6.45	5.23	900.1	-6.45	5.17	900.7	-6.45	5.10	900.1	-6.45	5.09	897.1
MAR 21	SEP 23	-6.00	5.21	849.0	-6.00	5.14	869.7	-6.00	5.10	879.5	-6.00	5.07	887.0	-6.00	5.05	891.0
MAR 7	OCT 8	-5.55	5.11	797.1	-5.55	5.08	828.7	-5.55	5.06	848.7	-5.55	5.04	862.1	-5.55	5.03	870.5
FEB 20	OCT 22	-5.11	5.03	737.1	-5.11	5.02	780.1	-5.11	5.01	807.5	-5.11	5.00	825.8	-5.11	5.00	837.1
FEB 7	NOV 5	-4.71	4.71	671.5	-4.71	4.71	724.6	-4.71	4.71	759.4	-4.71	4.71	784.4	-4.71	4.71	800.4
JAN 23	NOV 19	-4.35	4.35	609.4	-4.35	4.35	668.4	-4.35	4.35	707.0	-4.35	4.35	734.4	-4.35	4.35	753.0
JAN 10	DEC 3	-4.08	4.08	560.3	-4.08	4.08	620.3	-4.08	4.08	661.0	-4.08	4.08	690.3	-4.08	4.08	710.1
DEC 22		-3.92	3.92	532.0	-3.92	3.92	592.7	-3.92	3.92	633.9	-3.92	3.92	663.8	-3.92	3.92	684.0
		YEAR 288.025		R.I. .5480	YEAR 295.119		R.I. .5615	YEAR 300.110		R.I. .5710	YEAR 303.758		R.I. .5779	YEAR 305.961		R.I. .5821

NOTE - FOR ASPECTS WITH NEAR NORTHERLY AZIMUTHS, THE TIME AND SUN ANGLES ARE REVERSED.

LATITUDE [illegible] N
ASPECT NE - NW

SLOPE

		10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
		THETA 53.9		ALPHA 6.9	THETA 57.2		ALPHA 14.8	THETA 59.8		ALPHA 23.8	THETA 61.6		ALPHA 33.6	THETA 62.7		ALPHA 43.6
		SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
	JUN 22	-8.08	7.98	1012.3	-8.08	7.84	994.2	-8.08	7.64	968.2	-8.08	7.34	936.2	-8.08	6.92	900.6
JUN 1	JUL 12	-7.92	7.78	980.3	-7.92	7.59	958.8	-7.92	7.34	930.1	-7.92	6.99	896.2	-7.92	6.52	859.6
MAY 18	JUL 27	-7.65	7.46	925.9	-7.65	7.21	899.1	-7.65	6.88	866.4	-7.65	6.47	829.8	-7.65	5.95	791.9
MAY 3	AUG 10	-7.29	7.06	849.4	-7.29	6.72	816.1	-7.29	6.32	778.6	-7.29	5.84	739.1	-7.29	5.27	700.2
APR 19	AUG 25	-6.89	6.56	755.1	-6.89	6.17	715.1	-6.89	5.70	673.0	-6.89	5.16	631.3	-6.89	4.56	592.1
APR 4	SEP 9	-6.45	6.06	649.9	-6.45	5.60	604.0	-6.45	5.06	558.5	-6.45	4.46	515.6	-6.45	3.83	477.2
MAR 21	SEP 23	-6.00	5.54	539.0	-6.00	5.01	488.8	-6.00	4.41	441.6	-6.00	3.76	399.2	-6.00	3.10	363.0
MAR 7	OCT 8	-5.55	5.03	431.2	-5.55	4.42	378.8	-5.55	3.76	331.6	-5.55	3.06	291.3	-5.55	2.36	258.6
FEB 20	OCT 22	-5.11	4.52	333.8	-5.11	3.85	281.2	-5.11	3.12	236.0	-5.11	2.37	199.3	-5.11	1.64	171.1
FEB 7	NOV 5	-4.71	4.05	252.0	-4.71	3.30	201.1	-4.71	2.50	159.3	-4.71	1.69	127.2	-4.71	.92	103.9
JAN 23	NOV 19	-4.35	3.63	190.2	-4.35	2.81	142.1	-4.35	1.94	104.3	-4.35	1.06	76.9	-4.35	.25	58.6
JAN 10	DEC 3	-4.08	3.31	149.6	-4.08	2.43	104.2	-4.08	1.49	70.1	-4.08	.54	46.8	-4.08	-.33	32.4
	DEC 22	-3.92	3.11	127.0	-3.92	2.19	83.7	-3.92	1.19	52.1	-3.92	.18	31.5	-3.92	-.72	19.7
		YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
		204.705		.3895	189.885		.3613	175.868		.3346	163.167		.3104	152.057		.2893

SLOPE

		60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
		THETA 63.0		ALPHA 53.2	THETA 62.6		ALPHA 62.0	THETA 61.9		ALPHA 69.7	THETA 60.9		ALPHA 76.3	THETA 59.7		ALPHA 81.9
		SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
	JUN 22	-8.08	6.35	863.8	-8.08	5.68	828.2	-8.08	4.99	795.3	-8.08	4.33	766.2	-8.08	3.74	740.6
JUN 1	JUL 12	-7.92	5.94	822.7	-7.92	5.28	787.6	-7.92	4.62	755.6	-7.92	4.00	727.5	-7.92	3.45	702.9
MAY 18	JUL 27	-7.65	5.35	755.0	-7.65	4.72	720.8	-7.65	4.09	690.3	-7.65	3.52	663.8	-7.65	3.00	640.9
MAY 3	AUG 10	-7.29	4.66	663.7	-7.29	4.04	631.1	-7.29	3.45	602.7	-7.29	2.92	578.5	-7.29	2.44	557.8
APR 19	AUG 25	-6.89	3.94	556.9	-6.89	3.33	526.5	-6.89	2.76	500.8	-6.89	2.26	479.4	-6.89	1.83	461.5
APR 4	SEP 9	-6.45	3.20	444.3	-6.45	2.60	416.9	-6.45	2.06	394.5	-6.45	1.59	376.3	-6.45	1.19	361.3
MAR 21	SEP 23	-6.00	2.46	333.4	-6.00	1.87	309.7	-6.00	1.35	291.0	-6.00	.91	276.2	-6.00	.54	264.4
MAR 7	OCT 8	-5.55	1.71	233.1	-5.55	1.14	213.6	-5.55	.64	198.9	-5.55	.24	187.6	-5.55	-.10	178.8
FEB 20	OCT 22	-5.11	.97	150.3	-5.11	.41	135.1	-5.11	-.06	124.2	-5.11	-.43	116.2	-5.11	-.74	110.2
FEB 7	NOV 5	-4.71	.25	87.9	-4.71	-.31	77.0	-4.71	-.75	69.5	-4.71	-1.09	64.3	-4.71	-1.35	60.6
JAN 23	NOV 19	-4.35	-.44	46.9	-4.35	-.98	39.5	-4.35	-1.38	34.9	-4.35	-1.69	31.8	-4.35	-1.91	29.7
JAN 10	DEC 3	-4.08	-1.03	24.0	-4.08	-1.55	19.3	-4.08	-1.92	16.5	-4.08	-2.18	14.9	-4.08	-2.36	13.7
	DEC 22	-3.92	-1.44	13.5	-3.92	-1.95	10.3	-3.92	-2.28	8.6	-3.92	-2.50	7.6	-3.92	-2.66	7.0
		YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
		142.571		.2713	134.591		.2561	127.955		.2434	122.463		.2330	117.871		.2243

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 50 N
ASPECT SE - SW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	45.8		5.8	41.4		10.7	37.1		14.8	32.9		18.2	28.8		21.2
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	7.38	1023.6	-8.08	6.79	1023.4	-8.08	6.30	1019.5	-8.08	5.87	1011.8	-8.08	5.51	1000.7
JUN 1 JUL 12	-7.92	7.25	999.6	-7.92	6.68	1003.3	-7.92	6.20	1003.1	-7.92	5.79	998.8	-7.92	5.44	990.8
MAY 18 JUL 27	-7.65	7.02	958.2	-7.65	6.49	968.2	-7.65	6.04	973.9	-7.65	5.66	975.1	-7.65	5.33	972.1
MAY 3 AUG 10	-7.29	6.72	898.3	-7.29	6.24	916.6	-7.29	5.83	930.0	-7.29	5.48	938.5	-7.29	5.18	942.1
APR 19 AUG 25	-6.89	6.38	822.1	-6.89	5.94	849.4	-6.89	5.58	871.5	-6.89	5.26	888.0	-6.89	5.00	899.2
APR 4 SEP 9	-6.45	6.00	734.0	-6.45	5.62	770.2	-6.45	5.30	800.7	-6.45	5.03	825.2	-6.45	4.80	843.9
MAR 21 SEP 23	-6.00	5.61	637.7	-6.00	5.29	681.5	-6.00	5.02	719.5	-6.00	4.79	751.1	-6.00	4.59	776.5
MAR 7 OCT 8	-5.55	5.23	540.3	-5.55	4.96	589.9	-5.55	4.73	633.7	-5.55	4.54	671.0	-5.55	4.38	701.9
FEB 20 OCT 22	-5.11	4.85	448.8	-5.11	4.63	502.1	-5.11	4.46	549.6	-5.11	4.31	590.8	-5.11	4.18	625.5
FEB 7 NOV 5	-4.71	4.50	368.7	-4.71	4.34	423.5	-4.71	4.20	472.8	-4.71	4.09	516.1	-4.71	4.00	553.1
JAN 23 NOV 19	-4.35	4.20	305.6	-4.35	4.09	360.4	-4.35	3.99	410.2	-4.35	3.91	454.2	-4.35	3.85	492.1
JAN 10 DEC 3	-4.08	3.98	262.3	-4.08	3.90	316.4	-4.08	3.83	365.8	-4.08	3.78	409.6	-4.08	3.74	447.7
DEC 22	-3.92	3.84	237.5	-3.92	3.78	291.0	-3.92	3.74	339.8	-3.92	3.70	383.3	-3.92	3.67	421.3
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	233.752		.4447	246.528		.4690	257.487		.4899	266.457		.5070	273.457		.5203

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	25.0		23.7	21.5		25.8	18.3		27.7	15.4		29.4	12.7		30.8
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	5.20	986.9	-8.08	4.93	971.0	-8.08	4.70	954.0	-8.08	4.50	936.3	-8.08	4.32	918.5
JUN 1 JUL 12	-7.92	5.15	979.7	-7.92	4.89	966.3	-7.92	4.66	951.4	-7.92	4.47	935.7	-7.92	4.29	919.6
MAY 18 JUL 27	-7.65	5.05	965.5	-7.65	4.81	956.2	-7.65	4.60	944.9	-7.65	4.41	932.4	-7.65	4.25	919.1
MAY 3 AUG 10	-7.29	4.92	941.6	-7.29	4.70	937.7	-7.29	4.50	931.2	-7.29	4.33	923.0	-7.29	4.18	913.5
APR 19 AUG 25	-6.89	4.77	905.5	-6.89	4.57	907.8	-6.89	4.40	906.9	-6.89	4.24	903.6	-6.89	4.11	898.5
APR 4 SEP 9	-6.45	4.60	857.1	-6.45	4.43	865.6	-6.45	4.28	870.4	-6.45	4.15	872.3	-6.45	4.03	871.8
MAR 21 SEP 23	-6.00	4.42	796.1	-6.00	4.28	810.5	-6.00	4.15	820.7	-6.00	4.04	827.4	-6.00	3.94	831.3
MAR 7 OCT 8	-5.55	4.25	726.7	-5.55	4.13	746.0	-5.55	4.03	760.8	-5.55	3.94	771.7	-5.55	3.86	779.6
FEB 20 OCT 22	-5.11	4.08	654.1	-5.11	3.99	677.2	-5.11	3.91	695.5	-5.11	3.84	709.7	-5.11	3.78	720.7
FEB 7 NOV 5	-4.71	3.92	584.1	-4.71	3.86	609.6	-4.71	3.80	630.3	-4.71	3.75	646.8	-4.71	3.70	660.1
JAN 23 NOV 19	-4.35	3.79	524.2	-4.35	3.75	551.0	-4.35	3.71	573.1	-4.35	3.67	591.1	-4.35	3.64	605.7
JAN 10 DEC 3	-4.08	3.70	480.2	-4.08	3.67	507.5	-4.08	3.64	530.2	-4.08	3.62	548.9	-4.08	3.60	564.3
DEC 22	-3.92	3.64	453.8	-3.92	3.62	481.2	-3.92	3.60	504.1	-3.92	3.58	523.1	-3.92	3.57	538.8
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	279.445		.5221	282.247		.5370	284.552		.5414	285.815		.5438	286.278		.5447

NOTE - FOR ASPECTS ALONG WITH COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	51.9		8.6	53.1		17.6	53.6		26.5	53.4		35.1	52.7		43.0
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	7.67	1015.0	-8.08	7.19	1002.3	-8.08	6.63	984.7	-8.08	6.05	964.3	-8.08	5.45	942.9
JUN 1 JUL 12	-7.92	7.49	985.0	-7.92	6.99	971.0	-7.92	6.44	952.7	-7.92	5.85	932.1	-7.92	5.27	911.0
MAY 18 JUL 27	-7.65	7.20	933.8	-7.65	6.68	917.8	-7.65	6.12	898.4	-7.65	5.54	877.7	-7.65	4.96	857.0
MAY 3 AUG 10	-7.29	6.82	861.4	-7.29	6.28	842.8	-7.29	5.71	822.3	-7.29	5.13	801.5	-7.29	4.57	781.6
APR 19 AUG 25	-6.89	6.38	771.5	-6.89	5.82	750.4	-6.89	5.24	728.9	-6.89	4.66	708.3	-6.89	4.11	689.4
APR 4 SEP 9	-6.45	5.91	670.4	-6.45	5.33	647.0	-6.45	4.74	625.0	-6.45	4.17	605.0	-6.45	3.63	587.6
MAR 21 SEP 23	-6.00	5.43	563.0	-6.00	4.83	538.1	-6.00	4.23	516.1	-6.00	3.66	497.3	-6.00	3.14	481.6
MAR 7 OCT 8	-5.55	4.95	457.3	-5.55	4.33	432.1	-5.55	3.72	410.7	-5.55	3.15	393.4	-5.55	2.64	379.7
FEB 20 OCT 22	-5.11	4.48	361.4	-5.11	3.84	338.2	-5.11	3.22	316.1	-5.11	2.66	300.6	-5.11	2.16	288.9
FEB 7 NOV 5	-4.71	4.04	279.8	-4.71	3.38	255.6	-4.71	2.75	237.1	-4.71	2.19	223.5	-4.71	1.71	213.7
JAN 23 NOV 19	-4.35	3.66	217.5	-4.35	2.97	194.7	-4.35	2.34	177.9	-4.35	1.78	166.0	-4.35	1.31	157.9
JAN 10 DEC 3	-4.08	3.37	176.1	-4.08	2.67	154.5	-4.08	2.02	139.1	-4.08	1.47	128.6	-4.08	1.01	121.7
DEC 22	-3.92	3.16	152.9	-3.92	2.47	132.2	-3.92	1.83	117.6	-3.92	1.27	108.2	-3.92	.82	102.0
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	211.677		.4027	204.072		.3883	197.083		.3750	190.854		.3631	185.416		.3528

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	51.6		49.9	50.2		55.9	48.7		61.1	47.2		65.5	45.7		69.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	4.89	921.8	-8.08	4.37	901.8	-8.08	3.91	883.2	-8.08	3.50	866.2	-8.08	3.15	850.4
JUN 1 JUL 12	-7.92	4.71	890.4	-7.92	4.20	871.0	-7.92	3.75	853.1	-7.92	3.36	836.7	-7.92	3.01	821.6
MAY 18 JUL 27	-7.65	4.42	837.2	-7.65	3.93	818.9	-7.65	3.50	802.1	-7.65	3.12	786.8	-7.65	2.79	772.8
MAY 3 AUG 10	-7.29	4.05	763.0	-7.29	3.58	746.1	-7.29	3.16	730.9	-7.29	2.80	717.1	-7.29	2.49	704.6
APR 19 AUG 25	-6.89	3.61	672.5	-6.89	3.16	657.4	-6.89	2.77	644.0	-6.89	2.44	632.1	-6.89	2.14	621.4
APR 4 SEP 9	-6.45	3.15	572.5	-6.45	2.73	559.5	-6.45	2.36	548.2	-6.45	2.04	538.3	-6.45	1.77	529.4
MAR 21 SEP 23	-6.00	2.67	468.6	-6.00	2.27	457.7	-6.00	1.93	448.5	-6.00	1.63	440.6	-6.00	1.38	433.7
MAR 7 OCT 8	-5.55	2.20	368.8	-5.55	1.82	360.0	-5.55	1.50	352.9	-5.55	1.23	346.9	-5.55	1.00	341.7
FEB 20 OCT 22	-5.11	1.74	280.0	-5.11	1.38	273.2	-5.11	1.08	267.8	-5.11	.83	263.5	-5.11	.62	259.7
FEB 7 NOV 5	-4.71	1.30	206.7	-4.71	.97	201.5	-4.71	.69	197.6	-4.71	.46	194.5	-4.71	.28	192.0
JAN 23 NOV 19	-4.35	.92	152.3	-4.35	.61	148.4	-4.35	.36	145.6	-4.35	.15	143.4	-4.35	-.02	141.7
JAN 10 DEC 3	-4.08	.64	117.2	-4.08	.34	114.1	-4.08	.10	111.9	-4.08	-.09	110.3	-4.08	-.25	109.1
DEC 22	-3.92	.46	98.0	-3.92	.17	95.4	-3.92	-.05	93.6	-3.92	-.23	92.3	-3.92	-.38	91.3
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	180.704		.3438	176.610		.3360	173.033		.3292	169.879		.3232	167.047		.3178

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 50 N
ASPECT ESE - WSW

SLOPE

	10 PCT			20 PCT			30 PCT			40 PCT			50 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	47.5		7.8	44.7		14.8	41.5		20.8	38.3		25.9	35.1		30.3
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	7.37	1021.9	-8.08	6.71	1020.6	-8.08	6.13	1017.0	-8.08	5.61	1011.0	-8.08	5.16	1002.7
JUN 1 JUL 12	-7.92	7.22	996.2	-7.92	6.58	997.3	-7.92	6.01	996.1	-7.92	5.51	992.3	-7.92	5.08	986.0
MAY 18 JUL 27	-7.65	6.98	951.8	-7.65	6.37	956.9	-7.65	5.82	959.4	-7.65	5.34	959.2	-7.65	4.93	956.3
MAY 3 AUG 10	-7.29	6.66	888.3	-7.29	6.08	898.3	-7.29	5.57	905.8	-7.29	5.12	910.3	-7.29	4.73	911.8
APR 19 AUG 25	-6.89	6.29	808.0	-6.89	5.75	823.5	-6.89	5.27	836.4	-6.89	4.86	846.1	-6.89	4.50	852.5
APR 4 SEP 9	-6.45	5.89	716.0	-6.45	5.39	736.8	-6.45	4.95	754.9	-6.45	4.57	769.7	-6.45	4.24	780.9
MAR 21 SEP 23	-6.00	5.48	616.2	-6.00	5.02	641.6	-6.00	4.62	664.2	-6.00	4.27	683.4	-6.00	3.98	698.9
MAR 7 OCT 8	-5.55	5.07	516.3	-5.55	4.64	545.0	-5.55	4.28	571.0	-5.55	3.97	593.6	-5.55	3.71	612.4
FEB 20 OCT 22	-5.11	4.67	423.2	-5.11	4.28	453.9	-5.11	3.96	482.0	-5.11	3.69	506.7	-5.11	3.46	527.7
FEB 7 NOV 5	-4.71	4.29	342.4	-4.71	3.95	373.9	-4.71	3.66	402.8	-4.71	3.42	428.5	-4.71	3.22	450.5
JAN 23 NOV 19	-4.35	3.97	279.3	-4.35	3.66	310.6	-4.35	3.41	339.5	-4.35	3.20	365.3	-4.35	3.03	387.5
JAN 10 DEC 3	-4.08	3.73	236.4	-4.08	3.45	267.1	-4.08	3.22	295.5	-4.08	3.03	320.9	-4.08	2.88	342.9
DEC 22	-3.92	3.59	212.0	-3.92	3.32	242.2	-3.92	3.11	270.1	-3.92	2.93	295.1	-3.92	2.79	316.8
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	227.381		.4326	234.610		.4464	240.922		.4584	246.112		.4682	250.116		.4759

SLOPE

	60 PCT			70 PCT			80 PCT			90 PCT			100 PCT		
	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA	THETA		ALPHA
	32.0		34.1	29.1		37.3	26.4		40.1	23.9		42.5	21.6		44.6
	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	4.78	992.5	-8.08	4.44	980.7	-8.08	4.16	968.0	-8.08	3.91	954.8	-8.08	3.68	941.3
JUN 1 JUL 12	-7.92	4.70	977.7	-7.92	4.38	967.6	-7.92	4.10	956.5	-7.92	3.85	944.6	-7.92	3.64	932.3
MAY 18 JUL 27	-7.65	4.57	951.0	-7.65	4.26	943.8	-7.65	3.99	935.1	-7.65	3.76	925.5	-7.65	3.56	915.2
MAY 3 AUG 10	-7.29	4.40	910.6	-7.29	4.11	907.0	-7.29	3.86	901.7	-7.29	3.64	895.0	-7.29	3.45	887.4
APR 19 AUG 25	-6.89	4.19	855.8	-6.89	3.92	856.5	-6.89	3.69	854.9	-6.89	3.49	851.6	-6.89	3.32	847.1
APR 4 SEP 9	-6.45	3.96	788.7	-6.45	3.72	793.5	-6.45	3.51	795.7	-6.45	3.33	795.9	-6.45	3.17	794.5
MAR 21 SEP 23	-6.00	3.73	710.7	-6.00	3.51	719.2	-6.00	3.33	724.9	-6.00	3.17	728.3	-6.00	3.02	729.9
MAR 7 OCT 8	-5.55	3.49	627.4	-5.55	3.30	638.9	-5.55	3.14	647.5	-5.55	3.00	653.6	-5.55	2.88	657.7
FEB 20 OCT 22	-5.11	3.26	544.8	-5.11	3.10	558.6	-5.11	2.96	569.2	-5.11	2.84	577.3	-5.11	2.73	583.4
FEB 7 NOV 5	-4.71	3.06	468.8	-4.71	2.92	483.8	-4.71	2.80	495.8	-4.71	2.69	505.2	-4.71	2.60	512.5
JAN 23 NOV 19	-4.35	2.88	406.2	-4.35	2.76	421.7	-4.35	2.66	434.3	-4.35	2.57	444.4	-4.35	2.49	452.5
JAN 10 DEC 3	-4.08	2.75	361.6	-4.08	2.65	377.2	-4.08	2.56	390.0	-4.08	2.48	400.3	-4.08	2.41	408.7
DEC 22	-3.92	2.67	335.3	-3.92	2.58	350.8	-3.92	2.49	363.6	-3.92	2.43	374.0	-3.92	2.36	382.5
	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.	YEAR		R.I.
	252.978		.4813	254.830		.4848	255.831		.4867	256.148		.4873	255.938		.4869

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

LATITUDE 50 N
ASPECT E - W

SLOPE

	10 PCT		20 PCT		30 PCT		40 PCT		50 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	49.7	8.9	48.7	17.3	47.2	25.0	45.3	31.9	43.2	37.9

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	7.46	1018.7	-8.08	6.82	1012.8	-8.08	6.20	1004.3	-8.08	5.61	994.1	-8.08	5.08	982.7
JUN 1 JUL 12	-7.92	7.30	990.9	-7.92	6.67	985.6	-7.92	6.05	978.1	-7.92	5.48	968.9	-7.92	4.96	958.6
MAY 18 JUL 27	-7.65	7.04	943.2	-7.65	6.42	939.0	-7.65	5.82	932.8	-7.65	5.26	925.4	-7.65	4.76	916.9
MAY 3 AUG 10	-7.29	6.69	875.3	-7.29	6.08	872.4	-7.29	5.50	868.2	-7.29	4.97	863.0	-7.29	4.49	856.9
APR 19 AUG 25	-6.89	6.29	790.3	-6.89	5.69	788.9	-6.89	5.13	786.9	-6.89	4.62	784.2	-6.89	4.17	780.7
APR 4 SEP 9	-6.45	5.85	693.7	-6.45	5.28	693.9	-6.45	4.74	694.1	-6.45	4.26	693.9	-6.45	3.83	693.1
MAR 21 SEP 23	-6.00	5.41	590.1	-6.00	4.85	591.7	-6.00	4.33	593.9	-6.00	3.87	596.0	-6.00	3.47	597.6
MAR 7 OCT 8	-5.55	4.97	487.4	-5.55	4.42	490.2	-5.55	3.92	494.0	-5.55	3.49	497.9	-5.55	3.12	501.6
FEB 20 OCT 22	-5.11	4.53	392.7	-5.11	4.00	396.4	-5.11	3.53	401.3	-5.11	3.12	406.6	-5.11	2.78	411.6
FEB 7 NOV 5	-4.71	4.13	311.4	-4.71	3.61	315.6	-4.71	3.16	321.2	-4.71	2.78	327.3	-4.71	2.46	333.2
JAN 23 NOV 19	-4.35	3.78	248.6	-4.35	3.28	253.1	-4.35	2.85	259.1	-4.35	2.49	265.5	-4.35	2.19	271.7
JAN 10 DEC 3	-4.08	3.52	206.3	-4.08	3.03	210.9	-4.08	2.61	216.9	-4.08	2.27	223.4	-4.08	1.99	229.7
DEC 22	-3.92	3.36	182.5	-3.92	2.87	187.0	-3.92	2.46	193.0	-3.92	2.13	199.5	-3.92	1.87	205.7

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
219.654	.4179	219.807	.4182	219.951	.4185	219.965	.4185	219.763	.4181

SLOPE

	60 PCT		70 PCT		80 PCT		90 PCT		100 PCT	
	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA	THETA	ALPHA
	41.1	43.0	38.9	47.4	36.7	51.2	34.7	54.5	32.8	57.3

	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY	SR	SS	LY
JUN 22	-8.08	4.62	970.6	-8.08	4.20	958.1	-8.08	3.85	945.4	-8.08	3.54	932.8	-8.08	3.27	920.4
JUN 1 JUL 12	-7.92	4.50	947.6	-7.92	4.10	936.1	-7.92	3.75	924.3	-7.92	3.45	912.7	-7.92	3.19	901.1
MAY 18 JUL 27	-7.65	4.32	907.6	-7.65	3.93	897.8	-7.65	3.60	887.7	-7.65	3.31	877.5	-7.65	3.05	867.2
MAY 3 AUG 10	-7.29	4.07	850.0	-7.29	3.70	842.4	-7.29	3.39	834.4	-7.29	3.11	826.2	-7.29	2.87	817.8
APR 19 AUG 25	-6.89	3.78	776.5	-6.89	3.43	771.5	-6.89	3.14	765.9	-6.89	2.88	759.9	-6.89	2.66	753.6
APR 4 SEP 9	-6.45	3.46	691.5	-6.45	3.14	689.1	-6.45	2.87	686.0	-6.45	2.63	682.3	-6.45	2.43	678.1
MAR 21 SEP 23	-6.00	3.13	598.5	-6.00	2.84	598.5	-6.00	2.58	597.6	-6.00	2.37	596.0	-6.00	2.18	593.9
MAR 7 OCT 8	-5.55	2.80	504.4	-5.55	2.53	506.4	-5.55	2.30	507.4	-5.55	2.11	507.6	-5.55	1.94	507.2
FEB 20 OCT 22	-5.11	2.49	415.9	-5.11	2.24	419.3	-5.11	2.03	421.7	-5.11	1.86	423.3	-5.11	1.71	424.1
FEB 7 NOV 5	-4.71	2.19	338.3	-4.71	1.97	342.6	-4.71	1.78	345.9	-4.71	1.63	348.4	-4.71	1.49	350.1
JAN 23 NOV 19	-4.35	1.94	277.2	-4.35	1.74	281.9	-4.35	1.57	285.7	-4.35	1.43	288.6	-4.35	1.31	290.9
JAN 10 DEC 3	-4.08	1.76	235.3	-4.08	1.57	240.1	-4.08	1.42	244.0	-4.08	1.29	247.2	-4.08	1.18	249.7
DEC 22	-3.92	1.65	211.3	-3.92	1.47	216.1	-3.92	1.32	220.1	-3.92	1.20	223.3	-3.92	1.10	225.9

YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.	YEAR	R.I.
219.293	.4172	218.552	.4158	217.571	.4139	216.396	.4117	215.068	.4092

NOTE - FOR ASPECTS WITH WEST COMPONENTS, THE TIME AND SIGN OF SR AND SS ARE REVERSED.

Frank, Ernest C., and Lee, Richard
1966. Potential solar beam irradiation on slopes. U. S. Forest Serv. Res. Paper RM-18, 116 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

True solar time of sunrise and sunset and daily integrated potential insolation are presented in a series of tables for surfaces from latitudes 30° to 50° north, by 2° increments; at aspects from 0 to 360°, by 22.5° increments; on slopes from 0 to 100 percent, by 10-percent increments; and for 13 solar declinations or 24 dates during the year. Total potential insolation for a year and a radiation index based on annual values are given for each latitude, aspect, and slope combination. For inclined surfaces, latitude and change in longitude neccessary to locate "equivalent" horizontal surface are tabulated. Introductory notes present the mathematical equations upon which the tabulated values are based and describe the determination of local sunrise-sunset times and the use of the tables for latitudes 30° to 50° south.

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A Manual for Planning Structural Control of Avalanches

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U.S. Forest Service
Research Paper RM-19
May 1966

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
RAYMOND PRICE, DIRECTOR FORT COLLINS, COLORADO
FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

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ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
221 Forestry Building, CSU Fort Collins, Colorado

Frutiger, Hans, and Martinelli, M. Jr.
1966. A manual for planning structural control of avalanches. U. S. Forest Service Res. Paper RM-19, 68 pp., illus.

ERRATA

PREFACE: Snow density is expressed... Should read--

$0.100\ t/m^3 = 100\ Kg/m^3 = 0.10\ g/cm^3 = 10$ percent.

FOOTNOTES: Footnote 8 on page 15 should be footnote 14 on page 42; footnote 14 should be footnote 8.

On page 46, last line: footnote number should be 15 instead of 14.

FIGURES: Figure 25, page 25, Zone 1: Change (snow baffles) to (wind baffles).

Figure 38 (Nomograph 1): In the line drawing of the explanatory portion, change f_e to f_C, and S'_a to S'_Q.

U. S. Forest Service Research Paper RM-19 May 1966

A MANUAL FOR PLANNING STRUCTURAL CONTROL OF AVALANCHES

by

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Rocky Mountain Forest and Range Experiment Station[3]

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Hans Frutiger and M. Martinelli, Jr.

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INTRODUCTION

Regardless of the type of avalanche control employed, certain things are essential to the success of any such venture. First, detailed information on weather and snow conditions, and on the frequency and size of avalanches, must be available for each specific area to be controlled. These data usually can be obtained only by field observations in the avalanche zone. Second, once the structures are installed, routine field checks, in winter as well as in summer, are needed to determine whether alterations are needed in the original project layout, and to keep the structures in good repair. Sometimes changes in the snow cover are brought about by the structures themselves. Finally, continued research is needed to learn more about the basic physical and mechanical properties of the snow cover in steep terrain, and how modern engineering techniques can be used to give the most effective control system at the lowest cost.

This Manual should be considered a first edition that may be refined and expanded later if a comprehensive handbook is desired. Most of the field work in the United States was done in 1961-62 in the Colorado Rocky Mountains, but the techniques and procedures are applicable to most avalanche areas, and are based on many years of experience with avalanche control structures in Europe.

The Manual is divided as follows: PART I gives a classification of avalanches based on the features important for structural control, and explains how structures and forests can be used to control avalanches. PART II outlines the type of data needed to plan an avalanche control project, how to gather the information, and the type, arrangement, and design of structures. PART III is a case study of the Stanley Avalanche near Berthoud Pass, Colorado; it is an example of how data are used to develop an avalanche control project for a specific area. Since many of the statements made in Part III are based on only 1 winter's observations (1961-62), they should be considered tentative until more extensive field data are available. The APPENDIX contains the English translations of pertinent articles by Roch (1964), Schwarz (1960), and Frutiger and de Quervain (1964).[4] NOMOGRAPHS of four important formulas are in a pocket inside the back cover.

In 1962, Frutiger translated from German to English the Swiss guidelines and specifications for building permanent structures in the starting zones of avalanches (Swiss Federal Institute for Snow and Avalanche Research 1961). His translation of "Avalanche Control in the Starting Zone--Guidelines for the Planning and Design of Permanent Supporting Structures" was published by the Rocky Mountain Forest and Range Experiment Station as Station Paper 71. The present Manual supplements Station Paper 71, gives the reasoning and background information for many of the specifications set forth in the Guidelines, and presents data on other types of avalanche control structures. Most explanations and background material were intentionally omitted from the Guidelines for the sake of brevity.

The Guidelines cover only supporting structures in the starting zone because this is the most important type of structural control for avalanches in Switzerland. Because there is no way of knowing what type of control will be most effective or economical in other countries, however, all techniques used in avalanche control are summarized herein (Part I, Sect. 2, 3). In this way a comprehensive evaluation of structural control of avalanches can be based on knowledge of all the possibilities.

Complete definitions of all the special terms used in structural control are not given in this Manual, since they are available elsewhere (Seligman 1936, Bader et al. 1939, U.S. Forest Service 1961, Swiss Federal Institute for Snow and Avalanche Research 1961).[5]

---

[4] *Names and dates in parentheses refer to Literatude Cited, p. 60.*

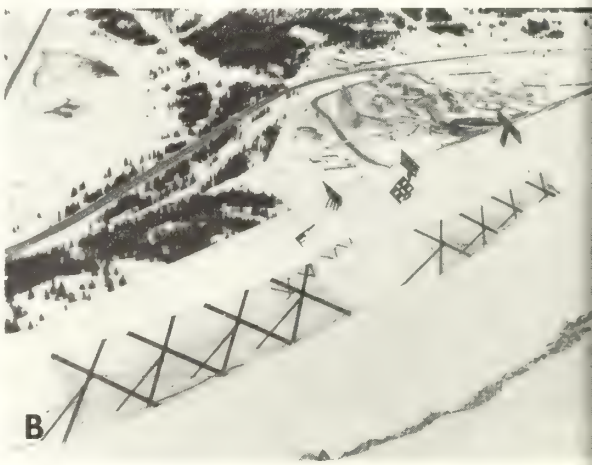
[5] *Mellor, Malcolm. Cold regions science and engineering. Part III, Sect. A3d. Avalanches. U. S. Army Materiel Command, Cold Regions Res. and Engin. Lab., Hanover, N. H. (In press.)*

It seems likely that structural avalanche control in the United States will follow a slightly different route from that developed in Europe. Here, because cheap manpower is not available in mountainous areas, the trend will favor structures that can be built with heavy machinery and a minimum of hand labor -- retarding and catching structures in the runout zone and the direct-protection structures such as avalanche sheds. Until this country's engineers gain experience and confidence, avalanche control projects based on supporting structures in the starting zone will probably be confined to easily accessible avalanches which threaten valuable property or heavy concentrations of people.

The avalanche control project started in 1963 by the Climax Molybdenum Company of Climax, Colorado, is a case in point: here, supporting structures were installed in the starting zone of a small avalanche that threatened buildings where many people and expensive machinery were housed. This is thought to be the first major avalanche control project in the United States to use supporting structures in the starting zone (fig. 1).

A survey was made of 80 avalanche paths along four major highways in Colorado to determine the possibilities for structural control (Frutiger 1964). Supporting structures were considered the obvious solution in 37 cases, and a possible solution in 15 more. Direct-protection structures were recommended for 15, and structural controls in the track or runout zone for 7. Structural control was not recommended for the remaining six paths.

Figure 1.--Avalanche control structures in starting zone of a small avalanche that threatens a mining operation near Climax, Colorado, A, summer view, shows height and location of structures; B, winter scene, illustrates uneven distribution of snow; C, a large earthen dam built farther downslope where slope is more gentle, crosses avalanche path to stop any avalanches that started below structures. More structures have been added in starting zone since these pictures were taken in October 1963.



PART I.

AVALANCHE CLASSIFICATION AND THE ROLE OF STRUCTURES AND FORESTS IN AVALANCHE CONTROL

1. Avalanche Classification for Structural Control Purposes

A description and classification of avalanches for structural control purposes will differ from that developed for basic research in the science of snow and avalanches such as given by de Quervain (1957), Seligman (1936), and the U. S. Forest Service (1961). Frequency of occurrence, for example, is completely neglected in the scientific classification, yet it is highly significant for planning structural avalanche control (figs. 2, 3).

The distinction between loose-snow and slab avalanches is only significant for control measures in the starting zone. This distinction is not important for diversion or other protective structures in the track and runout zone because, once moving at full speed, both of these dry-snow types look and behave exactly the same. The more important distinction, therefore, would be whether it is a dry-snow or a wet-snow avalanche, and whether it occurs frequently. Naturally, in a given area, all kinds of avalanches occur; but for structural control, it is important to find out which type is the most significant.

Schaerer (1962a, 1962b) also classified avalanches for structural control purposes.

Figure 2.--Aspen on a site where the climax forest is fir and spruce often indicates an avalanche zone. The aspen in the foreground undoubtedly are growing in the runout zone of an avalanche that many years ago destroyed the spruce-fir stand. A narrow path has been cut through the aspen stand by a recent small avalanche. The age of the aspen would indicate the date of the last big avalanche. One of the Jones Brothers avalanches, Jones Pass, Colorado. May 10, 1962.

Figure 3.--The aspen in the foreground had been growing on this site for at least 40 years. During the winter of 1961-62 they were knocked down by an avalanche. This vividly illustrates that long periods of inactivity are no assurance that certain avalanche areas are safe. Such avalanches have been called erratic because they run only under certain rather unusual conditions. The man near the right margin gives an impression of the size of the trees. West avalanche of Kendall Mountain near Silverton, Colorado. July 4, 1962.

His "dry-snow direct-action avalanche" corresponds to the "loose-snow avalanche" classification used in this report, his "dry-snow delayed-action avalanche" to the "slab avalanche," and his "spring-thaw avalanche" to the "spring or wet avalanche." His "wet-snow direct-action avalanche" is not significant in the Rocky Mountains of Colorado.

1.1 Loose-snow Avalanches

Loose-snow avalanches involve layers of snow with little or no internal cohesion. They start from a point or a very small area, and involve a formless mass of snow. The line between the snow that stayed in place and that that slid away is indefinite. On the basis of tests and observations of modern control structures in the European Alps for the past 15 years, this kind of snow movement appears to give the most trouble for avalanche control in the starting zone.

In the early days of snow and avalanche research, too little attention was given to the possibility of loose-snow slides. A theory of snow-cover stabilization, based on the slab-type avalanche -- the most dangerous type for skiers -- did not give enough consideration to the loose-snow avalanche. According to the slab-avalanche theory, the snowpack can be anchored to the ground by only a few structural "elements." This was the reason that some European avalanche control projects were installed with a minimum number of structures which were very widely distributed in a discontinuous, staggered arrangement, with large gaps left between the crossbeams of the structures. Experience has shown that these control works are not able to prevent the start of loose-snow avalanches. Furthermore, once started, the snow could not be stopped by the supporting planes of the structures; it flowed through the grate like water. Such slides, running between the structures, gained enough speed to turn into destructive avalanches.

Only a few people have had the chance to observe loose-snow avalanches. They occur on very steep, irregular slopes, and often start during or soon after snowstorms while the snow is still fluffy. Since there is no fracture line, it is difficult to locate the starting zone; a loose-snow slide can often be identified only by the damage it has caused to structures. Unfortunately, they have to be expected in any control area where steep slopes are present, and enough structures must be provided to stop them at their origin. Loose-snow avalanches are the reason why so many structures have to be installed. The width of the opening between crossbeams, the intervals between adjacent structures in the same line, and the distance between two lines of structures have to be kept within certain limits to control loose-snow avalanches.

1.2 Slab Avalanches

Slab avalanches involve layers of snow with decided internal cohesion. The sliding snow breaks away from the stable snow along a distinct fracture line -- a useful indicator of the starting zone.

Slab avalanches, also called simply "slabs," are the most common type, and usually start after a fresh snowfall has had a chance to settle and become more cohesive. Avalanche control in the starting zone would be much easier if only slabs were expected because, once a slab has formed, the snow cover has enough strength to support itself for a certain distance around each anchor point. The snow-pressure theory, developed by Haefeli (Bader et al. 1939) and Bucher (1948), is based on the idea that large forces can be transmitted within the snow cover. The cohesiveness of the snow cover permits Haefeli (Bader et al. 1939, p. 192 of Transl. 14) to state:

> From the viewpoint of construction and statics, the breaking up of a continuous supporting wall into separate elements leads in general to a higher concentration of the forces. The use of high-class materials thus permits a better utilization of their properties, and at the same time reduces surface weathering.

In other words, a relatively few, strong structures in an interrupted or discontinuous arrangement would be adequate for control and would be cheaper than continuous structures.

Either the dry, loose-snow avalanche or the slab can become a dust avalanche (airborne, powdery avalanche) if it reaches full speed in a track that is long and steep. The distinction between the dust avalanche and the wet-snow avalanche becomes important for control structures built in the track. It is very difficult to control airborne avalanches in the track. The Twin Lakes Avalanche on January 21, 1962, near Twin Lakes, Colorado, was an excellent illustration of the jumping power of a dry-snow avalanche moving at full speed.[6] About midway down its track this avalanche jumped a natural terrain barrier 100 feet tall.

1.3 Spring or Wet Avalanches

Spring or wet avalanches involve layers of wet snow with little cohesion. Like dry, loose-snow avalanches, they leave no sharp fracture line. Avalanches of wet snow move slowly but have great destructive power because of their weight.

Although this type of avalanche can be controlled easily in the track if terrain conditions are favorable, this does not help much when other types of avalanches also run in the same track. The spring or wet-snow avalanche flows along the ground at a low speed, and can be directed. Because it runs slowly, it does not travel far into the runout zone, and normally stops at the beginning of the transition zone between the lower end of the track and the beginning of the runout zone.

1.4 Important Parts of an Avalanche Area

For a discussion of avalanche control structures, the four parts of an avalanche area must be distinguished: catchment basin, starting zone, track, and runout zone (figs. 4-8, 21).

1.41 Catchment Basin

The top part of an avalanche area is called the catchment basin. Often it lies above timberline on bowl-shaped, steep slopes where heavy winds cause deep snow accumulations (see fig. 27). In other cases, it may be a broad, uniform area with few distinguishable terrain features (fig. 4).

1.42 Starting Zone

The actual places within the catchment basin where avalanches start are called starting spots or the starting zone. The area of the starting zone is less than the total area of the catchment basin. The starting zone of a slab avalanche shows a pronounced, well-defined fracture line; hence, the starting zone is also called the "fracture zone." Long-term observations show that the fracture lines of specific avalanches appear in the same general area year after year. Such observations are needed to delineate the starting zone of a particular avalanche. The fracture lines of many avalanches lie near the roll of snow that forms just to the lee of the steep alpine rimlands. Downhill from the roll there is a steep scarp where the snow normally fractures.

On irregular slopes, the fracture zones lie on the convex parts of the slope. In these transition zones, where the slope suddenly steepens, creep within the snow cover produces tensile stresses which eventually cause fracture.

---

[6] *Frutiger, Hans. Avalanche zoning. 1962. (Unpublished report on file at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.)*

Figure 4.--A typical areal or unconfined avalanche. The track is as wide as the starting zone. This avalanche occasionally crosses the 1,100 feet of flat valley behind the lake and reaches the highway. Ironton Park Avalanche on Red Mountain Pass, Colorado. July 3, 1962.

Figure 5.--The spruce and fir stand is not dense enough to prevent avalanches. It is difficult to locate the starting spots and tracks of this type of areal or unconfined avalanche. Floral Park Avalanche, Berthoud Pass, Colorado. April 25, 1962.

Figure 6.--Fracture spot at the border of an opening in the stand of young trees. One tree is tilted down by moving snow. Stick indicated by arrow is 1 meter long. Floral Park Avalanche, Berthoud Pass, Colorado. April 25, 1962.

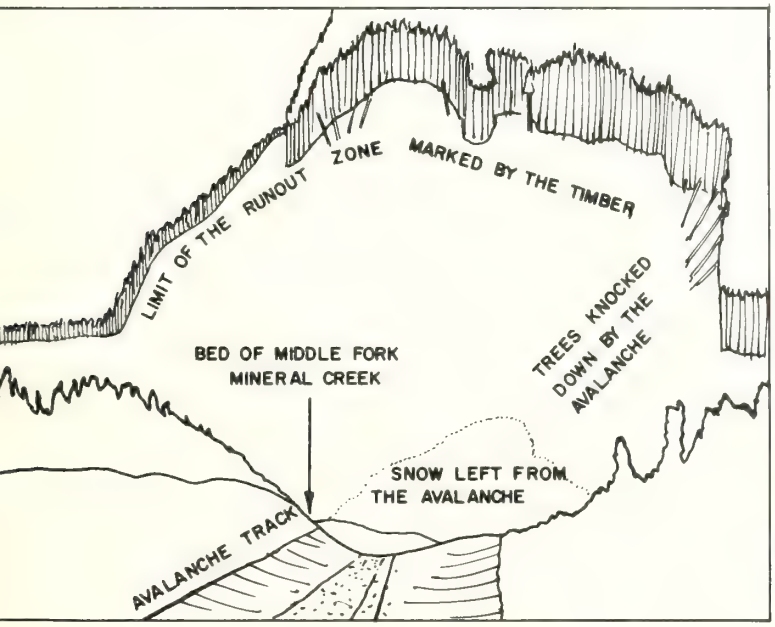

LIMIT OF THE RUNOUT ZONE MARKED BY THE TIMBER
TREES KNOCKED DOWN BY THE AVALANCHE
BED OF MIDDLE FORK MINERAL CREEK
SNOW LEFT FROM THE AVALANCHE
AVALANCHE TRACK

Figure 7.--How far does the runout zone extend? Vegetation is a good indicator of the limits of the runout zone. This avalanche hit the bottom of Mineral Creek valley while moving at full speed and stopped abruptly. The zone influenced by the avalanche extends 500 feet (150 m) from the creek up the opposite slope. Ophir Pass East, No. 3; 1 mile west of Burro Bridge. July 3, 1962.

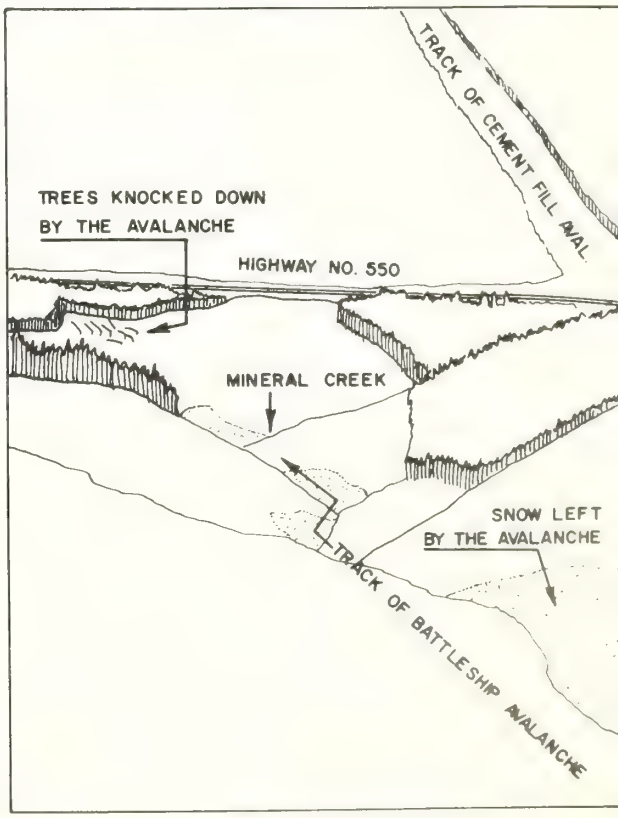

TRACK OF CEMENT FILL AVAL
TREES KNOCKED DOWN BY THE AVALANCHE
HIGHWAY NO. 550
MINERAL CREEK
SNOW LEFT BY THE AVALANCHE
TRACK OF BATTLESHIP AVALANCHE

Figure 8.--The runout zone of Battleship Avalanche extends from the valley 525 feet (160 m) up the opposite slope with a vertical rise of 240 feet (75 m). (See figure 21.) Battleship Avalanche, Red Mountain Pass, Colorado. July 3, 1962.

On irregular slopes the fracture zones lie on the convex parts of the slope. In these transition zones, where the slope suddenly steepens, creep within the snow cover produces tensile stresses which eventually cause fracture.

Some starting zones are well defined and easily located, as illustrated by the Stanley Avalanche, which has a starting zone well defined by the terrain (see fig. 27). Other starting zones are rather poorly defined; it is not at all obvious where the avalanches start, and long-term, detailed winter observations are needed to locate the spots to be controlled. The Ironton Park and Floral Park Avalanches (see figs. 4-6) are examples of this type.

The extent of the starting zone varies from little spots to widespread areas. The area of the starting zone determines how many supporting structures will be needed to control the avalanche as well as the cost of a control project.

Slopes steeper than 62 percent should be considered avalanche prone. The steepest slope that can be controlled is about 120 percent; cliffs cannot be controlled. Irregular and rugged terrain is difficult to control. Slopes between 30 and 62 percent are especially troublesome when planning avalanche control for villages and other critical areas. Often such slopes have no avalanches for decades, and the people become overconfident and careless. Wechsberg (1958) relates the story of several such catastrophes.

1.43 Avalanche Track

When first released, snow masses flow in a shallow layer and follow any depression in the slope; as momentum increases, the snow often concentrates in gullies, couloirs, or other marked paths. The path the avalanches usually follow is called the avalanche track.

Where the track is well defined, the avalanche will follow the same track every time. These are called channeled avalanches. When the slope is more or less uniform, the snow masses may take different routes or they may spread out over a wide area. These are unconfined avalanches or avalanches with an indefinite track. The track of an unconfined avalanche can be as wide as the starting zone (see fig. 4). On tracks that are not definite, the dust avalanche is very hazardous because it does not follow any set path and may come down where it is not expected. On the other hand, a wet-snow avalanche always follows the same track. Different types of avalanches coming down the same mountain may follow different paths according to their flow mechanism. The track of the airborne, dust avalanche is more or less straight while the damp avalanche follows every curve of the gully.

1.44 Runout Zone

The zone where avalanches naturally stop is called the runout zone. The terminus of avalanches in the same track varies, depending on the size and type of avalanche. The lower limit of the runout zone may not be reached for several years, but under extreme conditions, a big avalanche will go much farther than might be expected. Terrain features typical of runout zones are: (1) the lower end of an avalanche slope where the slope becomes more gentle, (2) the alluvial fan of a gully, and (3) the flat valley floor. In special cases the runout zone can extend part way up the opposite slope (see figs. 7-8). On cone-shaped alluvial fans, the paths of avalanches are indefinite; the direction of the avalanche may be changed by wind or earlier snow deposits.

The zone of influence of an avalanche is not limited to the physical borders of the track and runout zone. The air pressure wave, called the avalanche blast, may cause damage in a wide area. All the surroundings that are under the influence of the avalanche blast belong to the runout zone. Because houses and highways often lie in this danger zone, it deserves special attention.

2. Avalanche Control by Means of Structures

2.1 Short History of the Use of Structures in Europe

Although many European mountain settlements could not exist without some type of avalanche control, the need to reestablish protective forests devastated by logging, fire, and overgrazing was the biggest incentive for intensive avalanche control in the Alps. In Switzerland, a law was passed in 1876 permitting federal financial aid for the reestablishment of protective forests. This made the first large-scale avalanche control projects possible. About the same time, forestry agencies in France and Austria began working in the field of avalanche control. Many different techniques were soon developed.

In the early days, barriers were built from materials found in place. Above timberline, control works were almost exclusively earth terraces, earth terraces with small dry-masonry footings, and dry-masonry walls. Below timberline, wooden poles were often driven into the ground in a checkered arrangement to protect young afforestations. Simple fences, rakes, and bridges built of round timber were also used. Some of these early avalanche control works were so well done that nobody speaks of them today because the avalanches were stopped, the forests reestablished, and it now seems impossible that it was ever otherwise.

The empirical approach gave way to the scientific study of snow and avalanches with the establishment of the Swiss Avalanche Research Commission in 1932, and the later development of the Swiss Federal Institute for Snow and Avalanche Research at Weissfluhjoch near Davos. A great deal of progress was made in the following years. Skiers started to make observations in areas previously considered inaccessible, and laid a foundation for many of the scientific studies to follow (Seligman 1936). Older types of structures were modified and improved, and useful theories of snow movement and pressures were developed.

After the disastrous avalanche winter of 1950-51, a new era began in avalanche control. Structures built with modern building materials were used almost exclusively. In the fall of 1950 the first snow nets were installed. They were made of wire rope netting, and were supported by wooden poles. The next year the first aluminum snow bridges were constructed. At the same time, a concrete company made the first attempt to build snow bridges from prestressed concrete members. In 1955, an Austrian steel company in collaboration with the Austrian Avalanche Control Service brought out an all-steel snow bridge that was used extensively in Austria (Hanausek 1960), and was also installed in some Swiss projects. In 1957, the Electricité de France (EDF) used nylon nets for avalanche control. The nets were manufactured by a company that produced nylon nets for stopping airplanes on aircraft carriers.[7]

These modern structures have almost completely replaced the older ones because of the rising cost of manual labor. In recent projects three types of supporting structures, namely bridges, rakes, and nets, are commonly used (figs. 9-15). Masonry walls and terraces are still being used, but mostly for special purposes.

In 1961, a set of "Guidelines" (Swiss Federal Institute for Snow and Avalanche Research 1961) were published to cope with the complexities of design, layout, and arrangement of the new structures. Today there are about 3,000 avalanche control projects in Switzerland, and many others in Austria and France. Most of these projects use structures in the starting zone, following the motto "it is best to fight the root of evil."

It is surprising that a similar development did not take place in the mountainous areas of North America. During the mining era, the Rocky Mountains, Sierras, and Cascades were densely populated, and history gives an account of several avalanche disasters (Hult 1960). Perhaps the mining settlements did not last long enough for the need of avalanche protection to be fully realized.

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[7] *Aerazur Constructions Aeronautiques, Paris. Resultats pratiques acquis par les filets paravalanches en nylon depuis 1957 [Practical results gained by avalanche nylon nets since 1957]. Personal correspondence and office report, September 26, 1961.*

Figure 9.--Crude snow rake (upper left) made of round timber usually used in the afforestation zone. Kühnihorn, St. Antönien-Castels, Switzerland. April 2, 1959.

Figure 10.--Snow bridge (above) made of steel tubes and I-beams. Wilerhorn, Brienzwiler, Switzerland. August 11, 1960.

Figure 11.--Snow rake (lower left) made of aluminum. Wilerhorn, Brienzwiler, Switzerland. August 11, 1960.

Figure 12.--Snow bridge (above) is made of prestressed concrete. Kühnihorn, St. Antönien-Castels, Switzerland. April 2, 1959.

Figure 13.--Snow net (upper right) made of wire rope. Individual nets are triangular in shape and are hung on tubular steel posts that have a swivel joint at the bottom. Kneugrat, Braunwald, Switzerland. February 20, 1963.

Figure 14.--Snow net (lower right) made of wire rope on simple, round timber swivel posts. This type has been used successfully for protection of afforestations. Schilt, Stein (Toggenburg), Switzerland. July 14, 1959.

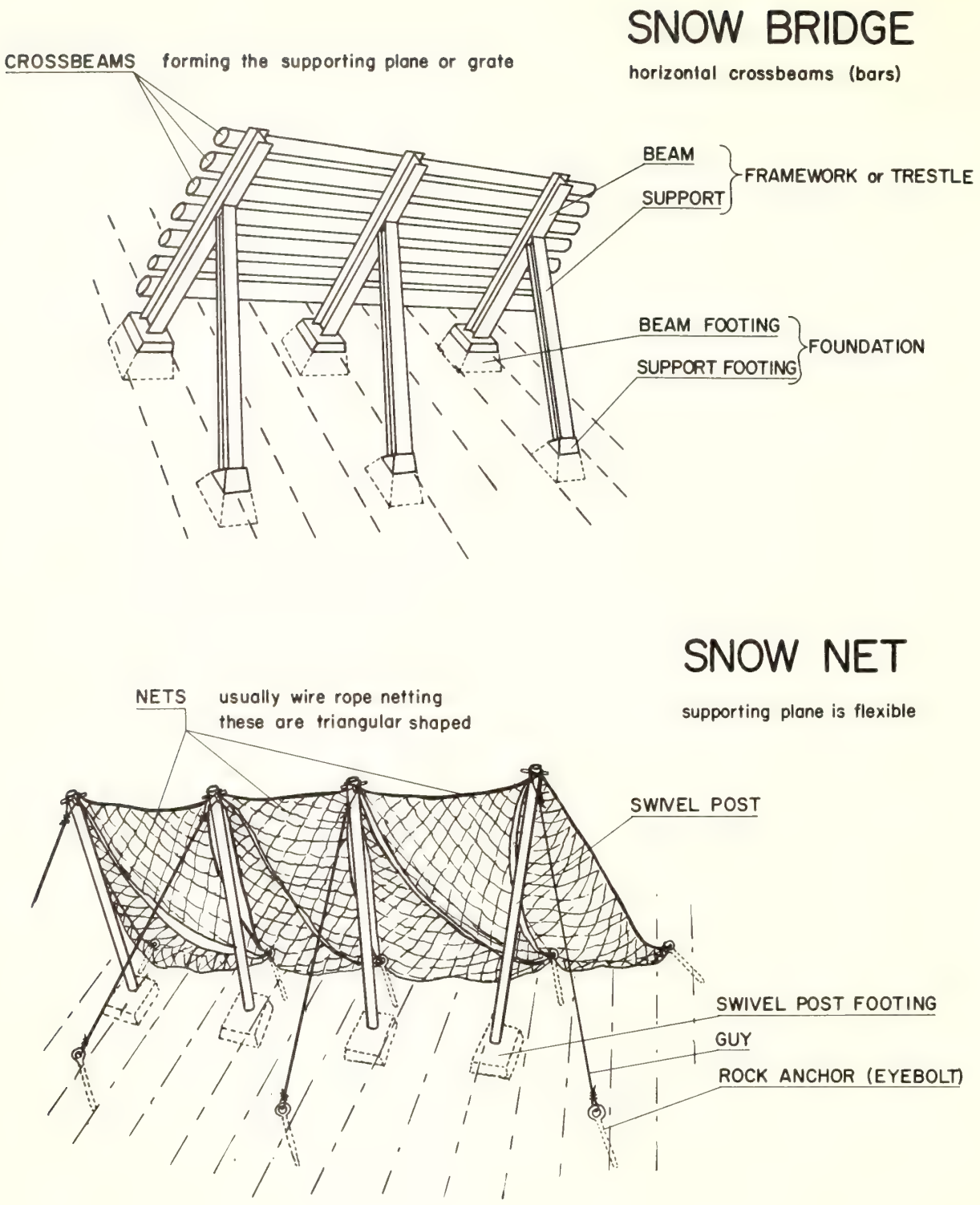
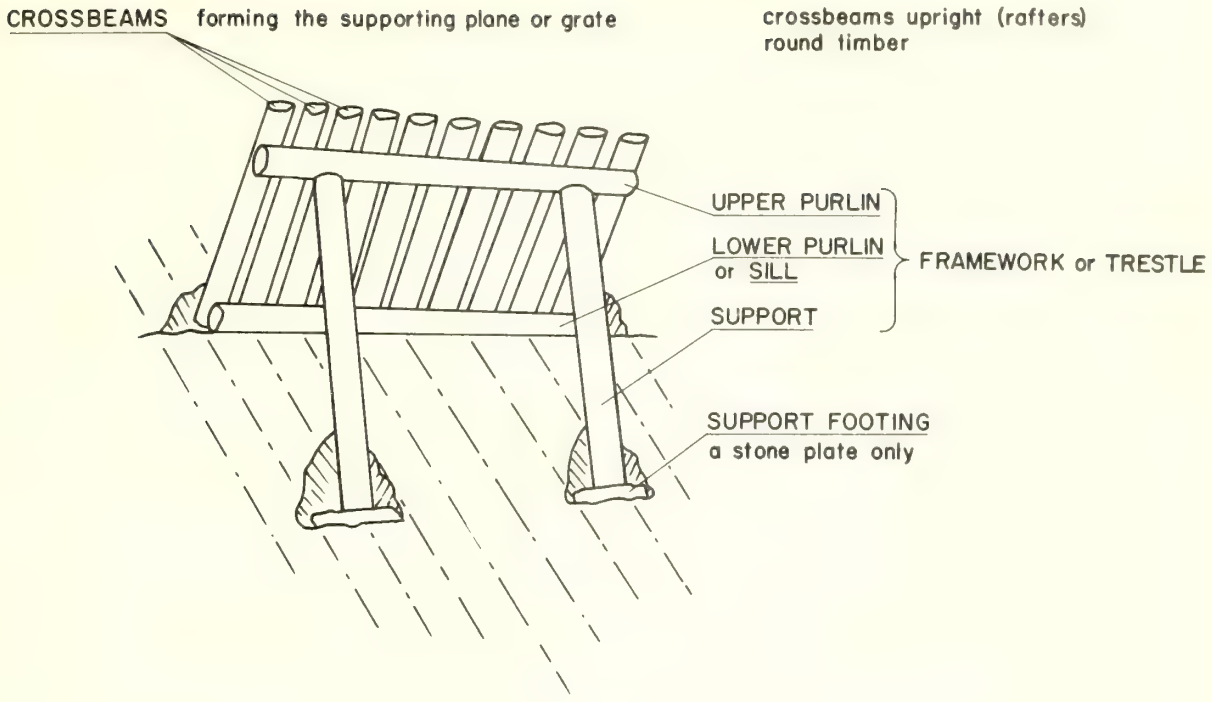


Figure 15.--Open supporting structures with various parts identified.

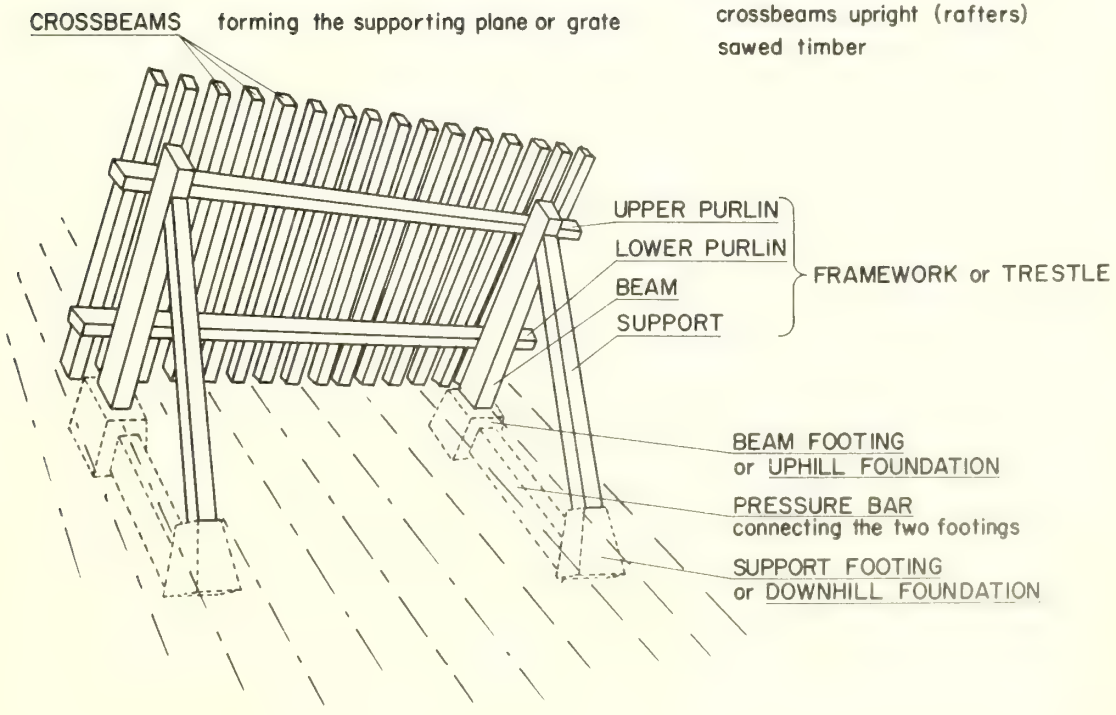
SNOW RAKE

crossbeams upright (rafters)
round timber



SNOW RAKE

crossbeams upright (rafters)
sawed timber



2.2 Supporting Structures in the Starting Zone

2.21 Purpose and Type

The purpose of avalanche control in the starting zone is to reduce the mass of avalanching snow to tolerable amounts and frequencies. How much avalanching can be tolerated must be decided for each avalanche control project. Toleration levels vary; greatest protection is needed for ski areas, roads, railroads, and permanent homes and villages. The Guidelines and this Manual give minimum acceptable levels of protection; these will be inadequate for exceptional conditions. Engineers familiar with design-storm concepts for planning bridges, culverts, and flood control projects know that complete protection for all weather conditions is extremely expensive and can seldom be attained.

Different classes of control structures are used in different parts of an avalanche zone. Supporting structures in the starting zone stabilize the snow cover by splitting up the tensile zones within the snowpack, and by holding the snow in place or reducing its movement to minor proportions. The primary purpose is to keep slab avalanches from starting and to stop loose-snow avalanches within a short distance.

There are many types of supporting structures capable of stabilizing the snow in the starting zone. Modern types, which include snow nets, snow rakes, and snow bridges (figs. 9-15), are made of steel, concrete, wood, or aluminum, and are called "open" or "framed" structures. Older structures were mostly massive terraces and walls.

The crossbeams of an open supporting structure form a plane, called the grate, which supports the snowpack. The crossbeams and the gaps between them can vary in width. A grate is, therefore, more or less penetrable to the snow, depending on the kind of crossbeams and the size of the gaps. The degree of penetrability of a grate can be expressed in terms of the density of the grate, that is, the ratio between the surface of the grate filled with structural material and the total surface of the grate. The flexible supporting plane of a snow net, for example, has an extremely low density. In contrast, the density of a masonry wall (massive structure) is one which signifies no airgaps.

The members of a supporting structure have to be designed to withstand the assumed snow-pressure forces. Because the snow pressure increases with the square of the snow depth, an empirical upper limit of 16 to 20 feet (5-6 m.) has been put on the height of these structures. Experience has also shown that inclining the grate downhill about 15 degrees from the perpendicular to the slope gives a better distribution of the forces acting on the members, especially the uphill footings. Vertical height (H_K) of the structure varies with the steepness of the slope (fig. 16). The slant height (B_K) of a structure is considered to be the significant and appropriate dimension for comparing the costs of different types.

The same slope effect made it necessary to give some standards in the Guidelines for snow nets. Because of the slack in these flexible structures, it was necessary to decide what would be considered the slant height of a net. In addition, it was necessary to define the length of the nets as the arithmetic average of the top and the bottom lengths because the supporting plane of a net is made up of a series of equilateral triangles arranged side by side. This results in the top of the supporting plane being shorter than the bottom. Nets were especially developed to provide light, flexible structures for use in steep, rugged, and barely accessible terrain where transportation of heavy structural parts would be difficult.

The joints between the major members of open, rigid structures may be either hinged or fixed. As a rule, the joint between the beam and the support is hinged (see fig. 15). Even experts do not agree, however, on the best type of joint to connect the superstructure (trestle, framework) to the foundations (footings). This point is too involved to discuss in this paper. For nets, the joint between the swivel post and the swivel post footing is either a universal or a ball-and-socket joint.

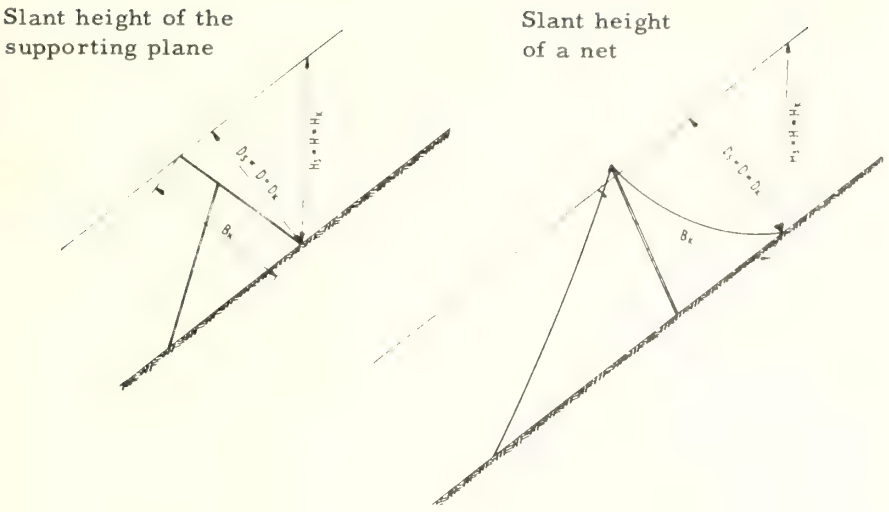


Figure 16.--The slant height (l_K), effective height (D_K), and vertical height (H_K) of rigid and flexible supporting structures.

2.3 Stresses Acting Upon Supporting Structures

2.31 Dynamic Stresses: Shocks and Impacts

Supporting structures are planned and arranged to minimize the movement of snow within the control area. It would be too expensive, however, to install enough structures to prevent all movement of the snow cover. The conventional distance between two lines of structures is 50-65 feet (15-20 m.). Even then, slides occasionally develop between the lines of structures, especially during snowstorms. Several times, slides of fine-grained, cohesionless snow have been observed in Swiss avalanche control areas. Loose-snow slides may flow through the grate of supporting structures and through the interval between two neighboring structures; even slab avalanches can start between lines of structures.[8]

It has been amply demonstrated that open, supporting structures cannot stop an avalanche traveling at full speed. The top row of supporting structures should therefore be very close to the uppermost fracture line. This row of structures must be installed within two or three times the vertical height of the structures below the upper fracture line. Some European projects have had to be completely rebuilt because of severe damage in places where too few structures were installed in an attempt to save material.

2.32 Static Stresses: Creep and Glide Pressure

2.321 Factors Influencing Snow Pressure.--Haefeli, who conducted the first experimental investigation on snow pressure, developed a general theory of the stresses acting in a snowpack on a slope (Bader et al. 1939, pp. 59-218 of Transl. 14), and presented a tentative formula for calculation of snow pressures. Nine years later, Bucher (1948) also developed a formula for the calculation of snow pressure; the two formulas give about the same results.

[8] *Frutiger, Hans. Eine Beobachtung über das Gleiten der Schneedecke im Bereich einer Erdterrasse. Int. Bericht 365, 11 april 1961. Eidg. Inst. für Schnee- und Lawinenforschung, Weissfluhjoch/Davos, Switzerland. [An observation on the gliding of a snowpack in the vicinity of an earth terrace. Unpublished report 365, Swiss Fed. Inst. for Snow and Avalanche Res.]*

In the Guidelines (Art. 27), the following formula derived from Haefeli's work is used:

$$S'_N = \gamma_S \cdot \frac{H_S^2}{2} \cdot K \cdot N \qquad (27)$$

S'_N component of snow pressure parallel to the slope per unit length of the supporting plane

γ_S average density of the snowpack (varies with the altitude and the aspect of the slope)

H_S snow depth measured vertically

K creep factor (a function of the angle of slope ψ and the snow density γ_S, as shown in the table below)

N glide factor (refers to the glide pressure and varies with the roughness of of the ground surface and the aspect of the slope)

Creep factor K as a function of γ_S and ψ

γ_S (kg/m³):	200	300	400	500	600
K/sin 2ψ:	0.70	0.76	0.83	0.92	1.05

To obtain the approximate values of K corresponding to the snow density, the given values $K / \sin 2\psi$ are multiplied by the values for $\sin 2\psi$.

Snow density at the time of maximum snow depth is fairly constant, and is assumed to be 270 kg/m³ for an altitude of 1,500 m. mean sea level, and an exposure of WNW-N-ENE. From the above table the creep factor, K, for a snow density γ_S of 270 kg/m³ and a slope angle, ψ, of 100 percent (45°) is found to be 0.74.

Substituting this in the formula gives:

$$S'_N = 0.27 \times \frac{H_S^2}{2} \times 0.74 N \text{ or approximately } S'_N = 0.10 \times H_S^2 \times N$$

General increase in snow density with altitude is computed by multiplying the right side of the above equation by the altitude factor, f_C, shown below:

Altitude above sea level	Altitude factor, f_C	Altitude above sea level	Altitude factor, f_C
<1,500	1.00	2,100	1.12
1,500	1.00	2,200	1.14
1,600	1.02	2,300	1.16
1,700	1.04	.	
1,800	1.06	.	
1,900	1.08	3,000	1.30
2,000	1.10	>3,000	1.30

This gives a relatively simple formula for snow pressure based only on easily determined factors. The above example has been developed for European conditions; a similar one can be developed for Rocky Mountain altitudes as data are collected.

Snow depth is the primary factor in determining snow pressure, since pressure varies as the second power of snow depth. Determining the depth and distribution of the snowpack is most important when an avalanche control area is being investigated. How to collect and analyze these data are discussed in Part III.

2.322 Creep and Glide of the Snow Cover. --Special attention must be given to the creep and glide movements of the snow cover. Unlike snow density, they vary greatly depending on the climate and the exposure of the slope, and the surface roughness at the site.

Haefeli gives a detailed description of his investigations on snow creep made during the winter of 1936-37 in the region of the Weissfluhjoch, Switzerland (Bader et al. 1939, p. 139 of Transl. 14). He used ping-pong balls as floats instead of a sawdust column.

In 1946, In der Gand (1954, 1957, 1959) started an intensive study of glide in connection with studies of the growth of young larch in the starting zone of avalanches. This work is being done in the test fields on the Dorfberg near Davos, Switzerland.

Frutiger investigated the creep and glide of the snow cover near supporting structures and terraces in the avalanche control projects at Mattstock near Amden,[9] [10] and at Kühnihorn near St. Antönien,[11] both in Switzerland. Martinelli (1960) published the results of some investigations on the creep and settlement of the snowpack made in the Rocky Mountains near Loveland Pass, Colorado.

The results of these investigations give only a rough idea, however, of what may happen in the snow cover during its evolution. In the case of an avalanche control project, the creep and glide factors must be determined in the control area. As stated above, the glide factor, especially, depends on weather and local ground-cover conditions. Extreme gliding has been observed several times during October and November in the Swiss Alps when heavy snow fell on the still-warm ground surface. Gliding is generally pronounced on south-facing slopes and on smooth, grassy surfaces. A dense stand of sedges on a steep slope soaked with melt water creates the worst possible conditions. Glide within the snowpack can be detected from the rifts that form in the area of greatest movement. Rifts in the snow cover are always an indication of extreme gliding.

2.33 The Different Aspects of Dynamic and Static Stresses

It is very unlikely that dynamic and static forces will act simultaneously. Shocks and impacts are the results of dry snowslides which take place during storms in midwinter. Although this is the time of greatest snow depth, the static pressures against structures -- called the "first type of loading" (fig. 17) -- are small.

Larger snow-pressure forces -- called the "second type of loading" (fig. 17) -- develop later when the snowpack, soaked with melt water, is settling rapidly. This is also the time of rapid glide motion.

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[9] *Frutiger, Hans. Lawinenverbauung "Mattstock"/Amden SG; Winterbeobachtungen 1959/60. Int. Bericht 351, 31 Oktober 1960. Eidg. Inst. für Schnee- und Lawinenforschung, Weissfluhjoch/Davos, Switzerland. [The "Mattstock" avalanche control project near Amden, SG; winter observations, 1959-60. Unpublished report 351, Swiss Fed. Inst. for Snow and Avalanche Res.]*

[10] *Frutiger, Hans. Lawinenverbauung "Mattstock"/Amden SG; Winterbeobachtungen 1960/61. Int. Bericht 394, 2 Oktober 1961. Eidg. Inst. für Schnee- und Lawinenforschung, Weissfluhjoch/Davos, Switzerland. [The "Mattstock" avalanche control project near Amden, SG; winter observations, 1960-61. Unpublished report 394, Swiss Fed. Inst. for Snow and Avalanche Res.]*

[11] *Frutiger, Hans. Lawinenverbauung "Kühnihorn"/St. Antönien-Castels; Winterbeobachtungen 1960/61. Int. Bericht 392, September 1961. Eidg. Inst. für Schnee- und Lawinenforschung, Weissfluhjoch/Davos, Switzerland. [The "Kühnihorn" avalanche control project near St. Antönien-Castels; winter observations, 1960-61. Unpublished report 392, Swiss Fed. Inst. for Snow and Avalanche Res.]*

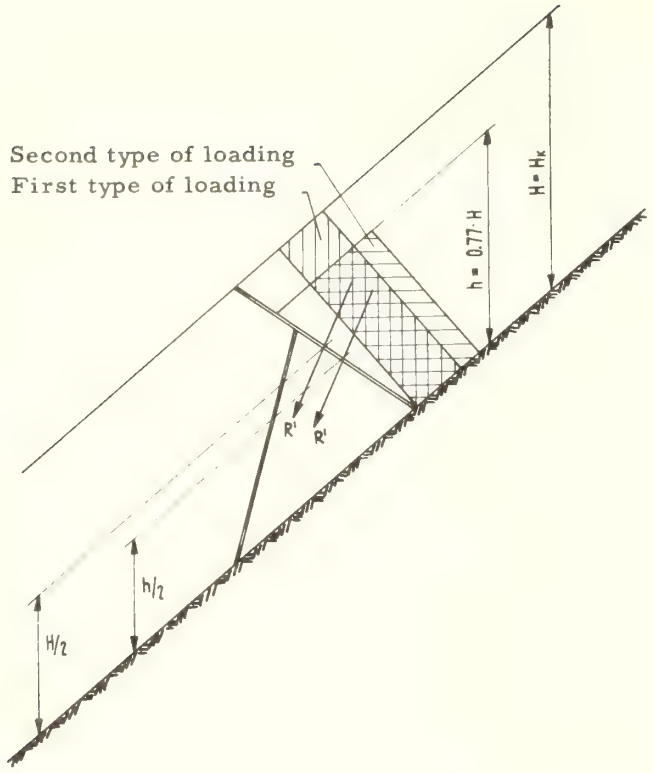

Figure 17.--Point of application of the resultant snow pressure force and distribution of the specific snow pressure for both types of loading.

These two aspects of the forces acting upon a supporting structure were described by de Quervain and Figilister (1953) as follows:

> As a rule the purpose of preventing avalanches is prevalent in midwinter when the snow depths, especially the new snow depths, reach their maximum. At that time snow-pressure forces normally are small because of the low density and low viscosity of the snow and because there is no glide all that time. In the period of high pressure (April, May, June, depending on the site), however, the occurrence of avalanches is less likely; the problem is to bring the structures through this period without damage.

2.4 Other Classes of Control Structures

It is not always economical and sometimes not even possible to install supporting structures in the starting zone. If the starting zone is too large, rugged, or remote in relation to the importance of the object to be protected, it is better to try other control possibilities in the lower parts of the avalanche area. These other classes of control structures, discussed below, were briefly referred to in the Guidelines (Art. 5).

2.41 Snowdrift Control

Structures to regulate drifting snow have a special place among avalanche control structures (Hopf and Bernard 1963). Normally, they are used in combination with supporting structures (figs. 18-20). In the Rocky Mountains, it is likely that modification of snowdrift patterns will become an essential part of any avalanche control measures in the starting zones.

The snowpack in the higher mountains, especially above timberline, will never be uniform. Wind action greatly modifies the snow deposition pattern, creating deep snow accumulations that make the control of many starting zones a real problem.

Figure 18.--Snow fences (upper right) on a flat ridge to catch drifting snow before it goes over the steep rim where it might become an avalanche. Clünas, Ftan, Switzerland. October 9, 1963.

Figure 19.--Jet roof (below) on a ridge to prevent a cornice. Clünas, Ftan, Switzerland. March 24, 1959.

Figure 20.--Wind baffles (lower right) on a ridge to prevent a cornice which menaces the supporting structures below. Kühnihorn, St. Antönien-Castels, Switzerland. January 15, 1958.

Two shapes of drifts are of special interest: the cornice and the roll. Only a few catchment basins can be found that do not have one or the other of these snow accumulation patterns (see fig. 27). Cornices and rolls steepen the snow surface, and their scarps are favorite starting spots for avalanches. Moreover, structures buried in deep accumulations are severely damaged by the settlement and creep of the snowpack in spring and early summer.

Snow fences, jet roofs (Düsendach), and wind baffles (Kolktafeln) are common types of drift structures. Snow fences (fig. 18) are used to catch drifting snow before it gets to spots where it would be troublesome. Jet roofs (fig. 19) are used to increase windspeed over the leeward edge of ridges where cornices and rolls tend to develop. Wind baffles (fig. 20) are used to create irregularities in the snow cover. The wind action around the baffles causes large wind scoops near the baffles and depositions in their lee. This is thought to prevent the buildup of excessive stresses within the snowpack. Wind baffles set in a line bordering the open flank of a structural control area are used to prevent a slab avalanche from spreading into the control area from neighboring, uncontrolled slopes (see Guidelines, fig. 10.2).

2.42 Guiding and Diversion Structures

Guiding and diversion structures may be useful in special cases, although they are generally of less importance than the other classes of control structures discussed in this Manual. They are constructed in or near the avalanche track, and are massive enough to withstand the impact of avalanches moving at full speed. The common types are the dam and the wall built of earth, stones, masonry, or concrete. A few diversion or guiding structures have been made from timber or steel, but it is usually not economical to use such materials since the structures have to be heavy enough to withstand impact loading.

Dams and walls may be built to keep the avalanche in its usual track or to divert it slightly out of its natural course. Depending on which function the structure is supposed to perform, they are called guiding structures or diversion structures. Guiding structures are useful to control sections of the track where curves or other natural obstacles may tend to divert the avalanche out of its usual path. The control works on Rogers Pass on the Trans-Canada Highway (Schaerer 1962b) include two guide walls to make sure the avalanche goes over an avalanche shed protecting the highway. In this way, the length of the shed was reduced. In Switzerland, some villages situated very close to avalanche tracks are protected by guide walls.

Diversion dams turn an avalanche away from an object to be protected. Diverting avalanches is a precarious and risky matter; too little is known about the behavior of avalanches encountering such structures to predict their effectiveness. If the angle of diversion is small, the terrain uniform and not very steep, and if enough material is available to build a high dam, it might be possible to control even dry-snow avalanches. Such structures are most effective, however, against wet-snow avalanches.

Diversion structures may also be considered a part of the group of retarding and catching structures that are used in the runout zone.

2.43 Retarding and Catching Structures

This type of structure, which stops the avalanche before it reaches the object to be protected, is effective only where the avalanche slows down naturally in a broad, flat section of the track or on a long, gently sloping runout zone. The most common types of retarding structures are mounds built of earth or stone, and fenders or bumpers usually built of concrete. Catching dams should be used in combination with a pit whenever possible. The control project on the Arzler Alm Avalanche near Innsbruck, Austria, is a fine example of how all of the above types can be used. Mounds are used in the runout zones of several avalanches on Rogers Pass in Canada (Schaerer 1962b). It must be emphasized, however, that there are only a few runout zones where such structures can be installed. Much of their effectiveness is lost if they are

installed at unfavorable sites. Schwarz (1960) and Roch (1964) say slopes should be less than 20° for retarding and catching structures to be effective. The problem can be best illustrated with four avalanche areas from the Colorado mountains (fig. 21):

	Stanley	Bethel	East Guadalupe	Battleship
Area of catchment basin (acres)	20	25	150	45
Average slope (percent):				
Whole track	50	52	45	45
Starting zone	60	70	76	63
Runout zone	32	40	20	32

The Stanley Avalanche (see fig. 27) has a small starting zone that is not too steep, a track that is regular and of medium steepness, and a runout zone above the lower loop of the highway that is about 1,000 feet (300 m.) long with an average slope of 32 percent. The runout zone is too short and too steep for retarding or catching structures. Moreover, the highway crosses the track again at a higher elevation. On the other hand, it would not be difficult

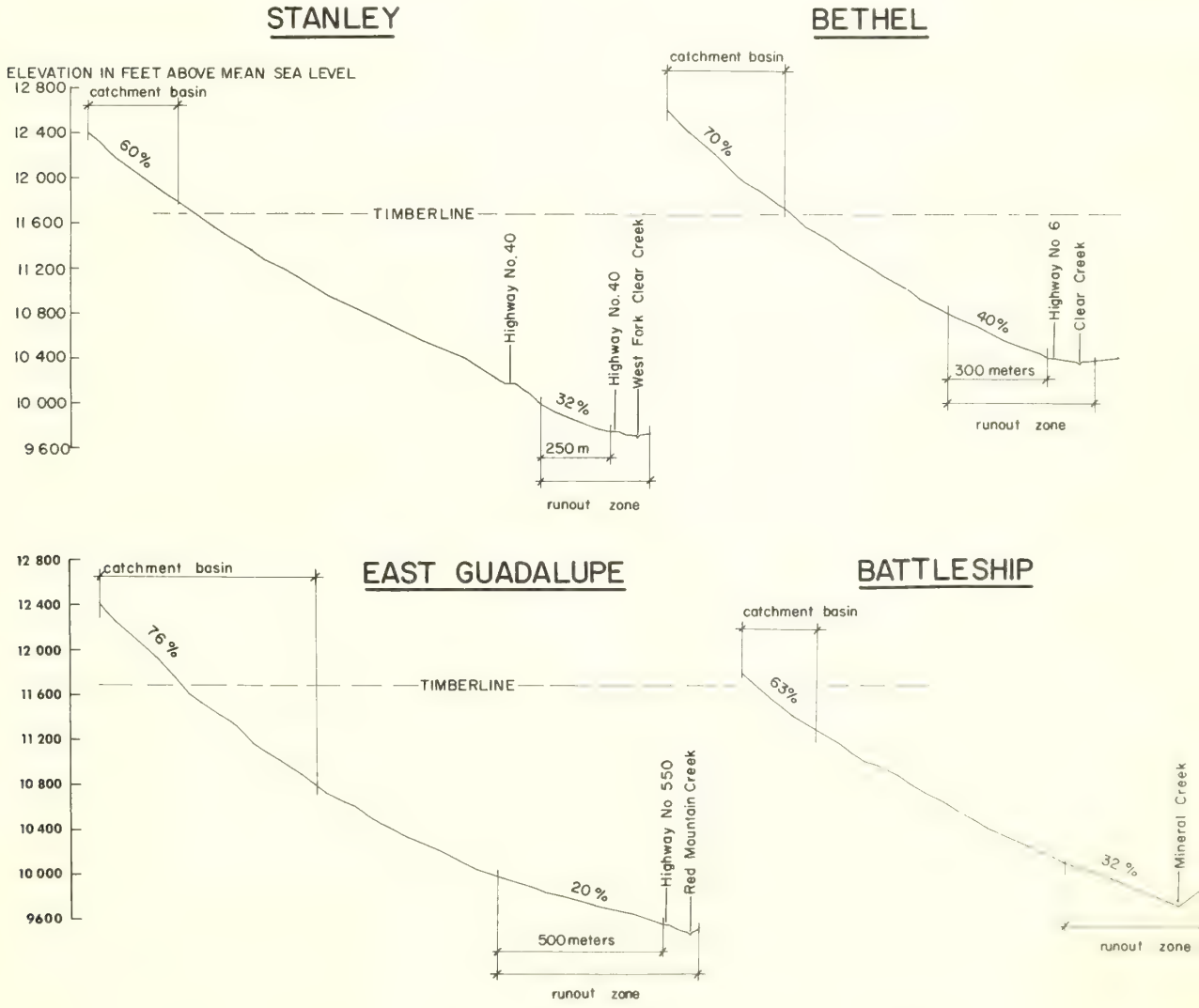

Figure 21.--Longitudinal profiles of four avalanche tracks. The examples used are the Stanley, Bethel, East Guadalupe, and Battleship Avalanches (see fig. 8).

to install supporting structures in the starting zone. Supporting structures in the starting zone and drift-control structures, then, would be the best type of control for the Stanley Avalanche.

In contrast, the East Guadalupe Avalanche along Highway 550 north of Red Mountain Pass has an extremely large, steep starting zone with cliffs exceeding 120 percent. The catchment basin of about 150 acres (60 ha.) has an average slope of 76 percent. The track is long, with an average slope of only 45 percent; the runout zone above the highway is long (1,600 feet; 500 m.) and gentle (20 percent). The large size and steepness of the starting zone makes supporting structures impractical. The length and gentle gradient of the runout zone, however, provide the features needed for successful retarding and catching structures.

The two earthen dams in the runout zone of the Bethel Avalanche[12] along Highway 6 west of Silver Plume, Colorado, should be mentioned here. These structures were built in the upper part of the runout zone, and were alined so that the upper one tends to divert the snow while the lower one acts as a catching structure. Although the dams do divert and catch large amounts of snow that would normally be deposited on the highway, the runout zone above them is too short and too steep (40 percent) for this type of structure to be highly effective. Should this avalanche run twice the same winter, the second avalanche probably would overrun the barriers because the snow from the first slide would greatly reduce their effectiveness.

In general, retarding and catching structures are useful where control of the starting zone would be too expensive, and where the avalanche runs too seldom to justify building an expensive avalanche shed. But they can give full protection only in very favorable terrain configurations. Normally, the effectiveness of retarding and catching structures is restricted to the reduction of snow removal.

2.44 Direct-Protection Structures

In some cases the terrain is so difficult and avalanches so frequent that the most economic solution to the problem is to protect the object directly. Direct-protection structures are not intended to retain, stop, divert, or slow down the avalanche; their only function is to directly protect the object. The most common type of direct-protection structure is the avalanche shed over highways and railroads (fig. 22). If the highway is put in a tunnel to avoid crossing an avalanche track, the tunnel would be another example of direct protection. In cases where the transmission lines have to cross avalanche tracks, the towers are sometimes protected by concrete walls built in the shape of a ship's prow (fig. 23). Other examples of direct-protection structures are earthen ramps or very strong walls and sheds on the uphill side of houses, built in the avalanche areas (fig. 24).

These structures give full protection, but they are very expensive. In addition, they do nothing to keep the avalanche from running and continuing to damage the forest and land. In Switzerland, they are used only when supporting structures or other types of structures cannot be used.

Direct-protection structures have to withstand the full force of a running avalanche. It is well known that avalanche forces are very great, but just how great is still unknown. Some years ago, the Swiss Institute for Snow and Avalanche Research started a program for the study of avalanche forces on an artificial avalanche track, the "Lawinengleitbahn" near Davos, and in the tracks of several natural avalanches (Roch 1962). Suggestions for the calculation of avalanche forces for different types of avalanches and for the design of avalanche sheds are given by Salm and Sommerhalder (1964), Schaerer (1965), and Voellmy (1955).

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[12] *Stillman, R. M. The Bethel Mountain avalanche diversion barrier, U. S. Highway 6, Loveland Pass, Colorado. 1961. Alta Avalanche Study Center Project G, Report No. 1, 4 pp., illus. Wasatch National Forest, U. S. Forest Service, Salt Lake City, Utah.*

Figure 22.--An avalanche shed over U. S. Highway 160 near Wolf Creek Pass, Colorado. Two avalanche paths cross the three-lane highway at this point. December 1, 1965.

Figure 23.--Heavy concrete pillars used as fenders or bumpers to protect the towers of a power line. Ardüs, Davos, Switzerland. May 6, 1963.

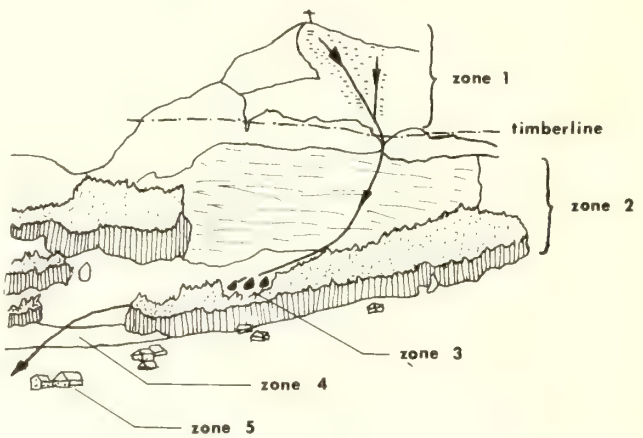
Figure 24.--Every [illegible] of the alpine settlement of St. Antönien has a mound of earth on the uphill side to protect it from avalanches. Gädmen-Matten-Meierhof, St. Antönien, Switzerland. July 30, 1963.

2.45 Combination of Several Classes of Control Structures

It is useful to combine, where possible, several classes of control structures on a single project. The control project on the Mattstock Avalanche near Amden, Switzerland, for example, uses four classes of control structures to protect the village (fig. 25). Permanent supporting structures (snow bridges and snow nets) and drift structures (wind baffles) were installed in the starting zone above timberline (fig. 25, zone 1). Trees were planted in the lower catchment basin since it is below timberline. Wide, earthen terraces were constructed to protect the young trees from excessive creep and glide of the snowpack, and to facilitate access to the plantation (fig. 25, zone 2). On a more gentle slope below the lower catchment basin, some retarding structures were installed. These earthen mounds (fig. 25, zone 3) are on pasture land where trees would be undesirable.

It is hoped that this combination of protective measures will give full protection to the village below. Moreover, there are other benefits: the pastures will no longer suffer from rockfall since they will be protected by the afforestation; the young trees will become a productive forest that renders more benefits to the owner than heavily used pasture land; and, the system of access roads built to bring in materials for the control structures will also be very useful for the management of the summer pastures.

Figure 25.--The Mattstock Avalanche control project, near Amden, Switzerland, uses four classes of control structures to protect the village.



ZONE 1: Catchment basin (starting zone) -- a bowl-shaped slope above timberline; site of the permanent supporting structures and drift structures.

ZONE 2: Steep slope below timberline -- area to be afforested; fine lines are earthen terraces to protect young trees from the glide of the snowpack.

ZONE 3: Pasture land -- a gentle section of the avalanche track where retarding structures (earthen mounds) have been built.

ZONE 4: Slot cut by the avalanche in the protective timber; area to be afforested.

ZONE 5: Area settled by people.

Center line of the avalanche track.

2.5 Avalanche Control by Means Other than Structures

In the United States, most avalanche control work involves the use of explosives in one form or another (LaChapelle 1960). Where there is easy access to the top of the avalanche paths, such as in ski areas, hand-placed charges are often used. A man on skiis or in a chair lift can toss a charge of high explosives on to the slope near the expected fracture line with accuracy and comparative safety. Where winter access is dangerous or very difficult, explosives may be placed in the starting zone during the autumn. These are wired to a safe spot so they can be detonated electrically when avalanche danger is high. Normally, two, three, or more series of explosives are put out so several avalanche cycles can be controlled each winter. The use of preplanted charges is probably more common in Europe than in the United States (Schild 1957).

Artillery is also used to control avalanches on inaccessible slopes. In western United States, 75 mm. pack howitzers and 75 mm. or 105 mm. recoilless rifles are commonly used for avalanche control along the highways and on ski slopes (U.S. Forest Service 1961). These guns have a long range (7,000 yards; 6,400 m.) and good accuracy. The surplus military ammunition produces shrapnel, however, so care must be taken to avoid damage to the cables or towers of ski lifts as well as other structures near the impact area.

Zone 1: (above) Starting zone (catchment basin) is controlled by different types of supporting structures (snow nets and bridges) and some drift structures (snow baffles). Different depths to which structures are buried indicate variability of snow depths in area.

Zone 2: (upper right) Steep slope below timberline will be afforested. Lines of earthen terraces will protect young trees by reducing the glide of snowpack. In right middle ground, six earthen mounds (retarding structures) have been erected on a gentle transition slope in the avalanche track.

Zone 3: (right) On a gentle section of avalanche track, used for pasture, earthen mounds (retarding structures) 5 m. (16.5 ft.) tall and 40 m. (130 ft.) in circumference at base have been constructed. In left middle ground, a backfill (fender) on the uphill side protects a stable.

A recently developed compressed-gas gun, called the Avalauncher (U.S. Forest Service 1964), which is now being tested, is lightweight, quiet, moderately accurate, and commercially available. Small cans of explosives are used as a projectile, with compressed inert gas as a propellant. The Avalauncher has a range of about 1,400 yards (1,300 m.) when a 12-foot barrel is used.

In Switzerland, explosives are used for avalanche control mostly on ski slopes where structures would interfere with ski activity. In such cases, the highly mobile, 8.1 cm. military mortar is used in preference to howitzers or recoilless rifles. In some other European countries, there are legal complications to the use of explosives for avalanche control.

In some cases, earthmoving equipment can be used to straighten and deepen the lower track or runout zone of an avalanche. This technique is most useful against wet-snow avalanches in areas where the objects to be protected are along the sides of the lower sections of the path. It would be less useful in areas of frequent, fast-moving, dry-snow avalanches.

Electrical and electronic devices have been used along highways and railroads to give warnings that avalanches have run (Hasler 1954, LaChapelle 1960, Schaerer 1962b). A detector is placed in the starting zone or the upper portion of the track. When this detector is disturbed, a signal along the road or railroad is activated, and traffic can be stopped before it reaches the avalanche zone.

Protective skiing is used to control small avalanches on or near many ski resorts. The mechanical action of the skis will often stabilize a new snow cover before avalanche hazard builds up. When snow accumulates on these slopes during periods of little or no ski use, it is sometimes possible to either stabilize the snow in place or to release unstable snow by skiing across the upper parts of the avalanche track (U.S. Forest Service 1961).

An elaborate avalanche-hazard warning service is provided the press and radio in the Alps and, to a lesser extent, in parts of Western United States and Canada. These bulletins describe existing snow conditions and give short-term forecasts of expected avalanche activity (Schild 1955, Wechsberg 1958). Although such warnings do not constitute avalanche control, they do help minimize the danger and inconvenience caused by avalanches.

3. The Role of Forests in Avalanche Control

A healthy, dense stand of trees is generally considered the best protection against avalanches. Just how trees stabilize the snow on steep slopes is not known, but it is a common observation that denuded slopes have more frequent avalanches than adjacent heavily forested ones.

Even a dense forest, however, cannot resist the tremendous force of large snow masses already in motion. Hence, to control avalanches that start above timberline, structures must be installed above timberline as well as in the area to be reforested.

Afforestations in avalanche areas that are entirely below timberline also need the help of structures to prevent the snowpack from gliding and pulling out the young trees before they are tall enough and vigorous enough to resist the snow-pressure forces. In avalanche tracks where trees are to be planted, the structures below timberline eventually will be replaced by the trees, but those above timberline must be considered permanent. Avalanche paths that have been created by careless timber cutting or burning offer the best chance for successful reforestation. The objection that trees at and near timberline grow too slowly to justify planting is not a valid argument. In fact, the slow growth rate is a strong argument for starting the job as soon as possible.

It is interesting to note that early avalanche control projects in Switzerland were established to protect existing forests and to permit reforestation of devastated areas. All Swiss avalanche control projects include the restoration of protective vegetation.

PART II.

BASIC CONSIDERATIONS IN PLANNING AN AVALANCHE CONTROL PROJECT

4. Observations and Surveys of the Avalanche Area

4.1 Snow Conditions

No avalanche control project should be started until a careful study has been made of the winter conditions in the project area. General information about winter conditions for the entire region as well as specific observations for the project site are important.

Usually it is not possible to get long-term observations for a particular control area. It is sometimes possible, however, to use long-term observations gathered at a study plot in the neighborhood to interpret the short-term spot observations taken at the project site. The more training and experience the interpreter has had, the better he will be able to extrapolate the general data to the project site.

Winter observations at the project site should extend over several years -- the longer the period the better. The following are among the more obvious questions that need to be answered:

> What is the maximum rate of snowfall for a given region?
> What are the general snow depths on the ground? What are the extremes?
> What are the average extreme snow depths for a control area?
> What are the wind patterns?
> What are the deposition patterns? How are the snow depths distributed?
> How does the wind influence the snow deposition?
> Are there possibilities of controlling snow deposition by drift structures?
> Where do the fracture lines of slab avalanches lie?
> Where are the starting spots of loose-snow avalanches? How often and how big do avalanches start?
> What would be the highest snow density?
> How much creep and glide is there in the snowpack?
> How long does the snow cover last?

Some people have the feeling that the starting zone of an avalanche is inaccessible in winter-time. That is not true. Extreme avalanche danger exists for only days or even hours. Between avalanche cycles there are long intervals when the experienced observer can penetrate the area without hazard. In the case of very remote, steep, or inaccessible spots, snow stakes can be used to permit reading snow depths from a distance with field glasses. The only difficulty is that the stakes usually disappear with the first avalanche.

For a given basin, the deposition patterns of the snow are rather constant from winter to winter. The cornices and rolls build up each winter at the same spots. An uncommon wind during a single storm, however, may temporarily change the usual pattern. Observations should extend over several years to be sure to include these unusual cases.

Snow settlement, creep, and glide measurements are important since they influence the load the structure must withstand. These data should be measured at the project site by one of several techniques. One technique requires a pit to the ground. Ping-pong balls are then placed in the walls of the pit at measured intervals in a vertical array above a marked point. The pit is back-filled with snow and left. Later in the spring the pit is dug again and the position of the balls is measured. Since creep and glide are most active in the spring, the pit must be dug at the time of maximum snow depth. In many areas this can be very laborious. Another technique involves the use of sawdust columns. At the time of maximum snow depth, a vertical hole is drilled through

the snow cover with a ram penetrometer, or a snow tube. A pointed wooden marker is dropped into the hole and driven into the ground to mark the spot. The hole is filled with sawdust. Later in the spring, after the snowpack has become isothermal and after the heavy spring settlement has taken place, the sawdust is exposed in a pit wall (see fig. 30), and creep and glide measured. Haefeli varied the second technique by using both ping-pong balls and sawdust (Bader et al. 1939).

Snow-density data should also be taken in any area where the density values or the altitude factor given in the Guidelines might not apply. The Federal snow sampler (Marr 1940) or 500 cm^3 cylinders (Bader 1962) are usually used to measure density.

4.2 Terrain Conditions

The cost of controlling avalanches with supporting structures depends primarily upon the extent and the terrain conditions in the starting zone. The form of the catchment basin and the kind of ground surface are factors that determine the spots likely to avalanche. As the terrain becomes more rugged, the prospects for successful control decrease. Slopes with cliffs are very difficult to control because loose-snow slides start in the cliffs. Starting zones below timberline can be controlled more economically than those above because of the possibility that an afforestation will eventually replace the structures. The accessibility of the area greatly influences transportation and labor costs. The surrounding terrain features also influence the type of transportation system (access road, cableway, or other methods).

Soil and rock conditions have to be explored thoroughly. Some decisions about the type of structure to be used can be made only after evaluating the soil and rock in the area. Nets, for example, can be used only if rock anchors can be placed in sound bedrock. If the ground is unstable (scree or talus), special foundations such as pressure bars have to be used. As a rule, bridges and rakes require bedrock within reach, which means the bedrock should not be deeper than 2 feet (1/2 m.). The quality of the bedrock has to be checked. If it is heavily fissured, it might be very difficult to drill the holes needed for the anchorage. Probe pits, and rock and soil tests (see Guidelines, appendix) give an estimate of subsurface conditions. Where structures have to be built on scree and detritus, the costs are appreciably higher than for those built on bedrock.

A survey of the area where structures are to be installed is recommended. It is preferable to have this survey done by the same engineer who will plan the structural control, because the field study forces him to make a thorough examination of the terrain conditions. The survey should answer the following questions:

> How big is the area to be controlled by structures?
> What are the exposure and the slope gradient?
> What are the possibilities and difficulties of access?
> What kind of soil and rock are present? Bedrock or scree?
> How deep is the detritus?
> Are there swamps or springs that may cause difficulties?

Much of these data are plotted on a large-scale map or a site plan of the area (see figs. 28, 29). The site plan also serves as a base for recording winter observations and for planning the arrangement of the structures. A scale of 1:500 to 1:2000 is needed, depending on the extent of the area and the kind of structural control.

5. Choice of Structure and Construction Materials

After the decision is reached that structural control is feasible for a given avalanche, the next decision concerns the type of structure. Where a high degree of protection from frequent, large avalanches is desired, either supporting structures in the starting zone or direct-protection structures are the logical choices. Which of these two types is a matter of comparative construction costs, with those costs governed primarily by the characteristics of the avalanche area.

Comparative costs for road or railroad protection in Switzerland (Frutiger and de Quervain 1964) have shown that 130 feet of avalanche shed costs the same as 1 acre of supporting structures (or 200 m. of shed per ha. of structures). Where a road or railroad crosses the same avalanche path more than once, or where an avalanche crosses a road on a wide front, supporting structures usually provide the highest degree of protection per dollar spent. For isolated buildings, high-tension transmission towers, and ski lift installations, direct-protection structures usually are the cheaper type of control.

Diverting and retarding structures or the use of explosives give satisfactory control in areas where less complete protection is acceptable and where avalanches are less frequent. This type structure is not effective on slopes steeper than 20 percent (see Sect. 2.4, p. 18; Roch 1964).

Supporting structures in the starting zone are the only type of structures that protect the avalanche track and the runout zone, as well as the only satisfactory system where reforestation is planned.

The type of supporting structure and the construction materials will depend on durability, exchangeability, maintenance, access, terrain features, and soils. Although not all factors can be discussed here, the most important properties of different types of supporting structures and building materials will be mentioned.

Any type of supporting structure -- open or massive -- should meet the following specifications:

> They should be at least as tall as the maximum snow depth expected under the worst conditions.
> There should be enough structures to control loose-snow avalanches.
> They must be strong enough to withstand dynamic and static pressures.

5.1 Open Supporting Structures

Although 80 to 90 percent of the structures in modern avalanche control areas are snow bridges, observations have indicated that snow rakes stop sluffs and resist snow pressures better (Roch and Sommerhalder 1961). Most avalanche control engineers consider the choice between rakes and bridges a matter of opinion, with cost the most important criteria. Either type requires a special pressure bar between the uphill and downhill footings in areas where bedrock cannot be reached (see fig. 15).

Snow nets (see figs. 13-15) should be used only in places where anchors can be placed in sound bedrock because the extreme tension forces on the guys require the best possible anchorage. Nets should not be used exclusively, however, for protecting large areas because the density of the supporting plane is not sufficient to prevent sluffs from flowing through and causing dangerous avalanches (Frutiger 1961).

Fences (see Sect. 10.1, p. 44, and fig. 31) may be useful in areas where extreme snow settlement is expected since the vertical configuration of these structures reduces the effect of settlement. On slopes, however, fences have less effective height than structures whose supporting grates are approximately normal to the slope.

5.2 Massive Structures -- Supporting and Direct-Protection

Massive supporting structures, such as walls, terraces, and dams made of earth, stone, or masonry, were once the prevailing structures used for avalanche control in the starting zone. Now they have been replaced almost entirely by open structures. For special purposes, however, they can still be very useful. If the slope to be protected is very steep or has cliffs in the upper portions, the topmost structures have to be strong enough to withstand falling chunks of snow and rock. In this case, massive structures are advantageous. Furthermore, massive structures are useful in deep snow accumulations where open structures are not strong enough to withstand the excessive snow-pressure forces. Here, a combination of a massive structure and an open one is recommended. For example, a steel fence mounted on top of a masonry or concrete wall gives a tall structure at modest costs, and is one solution for control of snow roll areas (see fig. 31).

No rigid design analysis is needed for most massive supporting structures. Normally, such types should be used only at sites where suitable rock for masonry can be found. Where suitable building material is absent, concrete could be used.

Of course, all structures subject to impact loading from moving avalanches have to be massive. This includes such structures as diversion dams, catching dams, and guiding and retarding structures. Avalanche sheds are the one type of massive structure that must be carefully designed to resist the dynamic forces of a moving avalanche (see Sect. 2.44, p. 22; Roch 1962, Voellmy 1955).

5.3 Construction Materials

Timber, steel, aluminum, concrete, and wire rope are used in the field of avalanche control engineering. Aluminum and prestressed concrete have been the most common materials. In recent years, however, there is a strong trend toward steel. The use of nylon is still experimental[13] (see Sect. 2.1, p. 9), and will not be discussed in detail in this Manual. Timber is still one of the most important building materials. It has been used from the very beginning of structural avalanche control, and is still the best for temporary supporting structures. Timber responds very well to snow pressure loads. It is strong, yet its great flexibility allows it to yield under heavy loads without permanent deformation. The main difficulty encountered with timber is its susceptibility to decay, which varies greatly with the species of wood and the climate of the site where it is used. Modern preservation methods (MacLean 1952), however, are highly effective in prolonging the useful life of most species of wood.

Experiences with steel in avalanche control areas in Europe show that corrosion under alpine conditions is slight and usually can be disregarded. In the United States, steel may become the most common building material for avalanche control. Where transportation is a problem, it might be more economical to use medium- to high-grade steel to reduce the weight.

Steel used in avalanche construction must be malleable enough to withstand the impacts of sluffs and slides during periods of low temperatures. This is particularly important for the grate, which is exposed directly to impact loading and to the very irregular forces of creep and glide. The framework is usually made from a high-grade steel with low to medium malleability.

Aluminum has been used in avalanche control work, primarily to reduce transportation costs in cases where such costs were disproportionately high. It was expected that the use of aluminum might be economical even though it costs about four times as much as steel per unit weight. Aluminum needs no protection against atmospheric influences. Unpainted aluminum structures are not desirable in areas where it is important to conserve the natural environment. Reflections of the sun or even of moonlight from the structures are visible for great distances.

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[13] *Frutiger, Hans. Rapport sur le voyage d'etude dans le Beaufortin (Savoie) pour faire connaissance des filets paravalanches en nylon. Int. Bericht 376, 19 Juni 1961. Eidg. Inst. für Schnee- und Lawinenforschung, Weissfluhjoch/Davos, Switzerland.* [*Report on a work trip into le Beaufortin Mountains (Savoy) to learn about nylon avalanche nets. Unpublished report 376, Swiss Fed. Inst. for Snow and Avalanche Res.*]

Some alloys of aluminum are subject to electrolytic corrosion if brought into contact with other metals (steel pins) and to chemical corrosion if embedded in concrete (footings). Therefore the properties of the alloy should be checked before it is used for avalanche control structures.

Concrete structures are very heavy, and special equipment is needed to assemble the structures at the erection site. A single beam weighs about a ton. Prestressed concrete members are subject to heavy transportation damage and therefore need very careful handling. The installed structures also need special protection if they are exposed to rockfall. Like aluminum, concrete structures need no protection against corrosion, and because of their weight damage by snow-pressure forces is not likely.

Wire-rope snow nets are the lightest structures in common use. A normal net 10 by 10 feet (3 by 3 m.) weighs about 66 pounds (30 kg.). The heaviest member is the steel-tube swivel post, which weighs 130 to 220 pounds (60-100 kg.). One or two men can backpack the whole snow net, and no special arrangements are needed for installation. The wire rope, made of galvanized steel wire, is made into snow nets, then coated with a green oil varnish, which not only protects it from corrosion but renders it quite inconspicuous.

6. Arrangement of Supporting Structures

The arrangement of supporting structures is based on an analysis of terrain and snow conditions. Since control projects must start at the top of the avalanche area and progress downslope, any numbering system for lines of structures or for individual structures should start at the top. The choice between continuous, interrupted, and staggered arrangement of structures is based mostly on the uniformity of the terrain and the type of structure used. Where there are numerous large rocks or knolls, a staggered arrangement is usually best. A continuous arrangement is easiest to use in uniform terrain, and is less subject to end effect forces. The interrupted and staggered arrangements have been used most often, but the trend now is toward a continuous arrangement because it gives better control of sluffs. Experience in Switzerland has also shown that when the heavy, prestressed concrete bridges (see fig. 12) are used, the continuous arrangement is more economical.

Individual structures should be built with their long axis perpendicular to the fall line at the structure site, whether an interrupted or a continuous arrangement is used. In an interrupted arrangement, the gap (interval) between adjacent structures built on the same contour line should be no more than 6 feet (2 m.). If adjacent structures are uphill or downhill from each other, the projection of the horizontal distance (interval) between the structures decreases the farther they are apart. When the slope distance between structures reaches 20 feet (6 m.), the interval finally reaches zero (see Guidelines, Art. 23).

When local areas of exceptionally deep snow, such as cornices and gullies, are encountered in an avalanche control area, special structures or arrangements may be needed (see Sect. 10.1, p. 44). In some cases snow fences or other types of drift structures may be helpful in controlling snow depths. The ultimate solution will usually vary from project to project.

Recent experience in Europe has shown slope distance between structures and width of the opening between members of the grate (as given in Guidelines, Art. 21, 58) are too great for complete protection. To prevent all avalanches, slope distance and width of opening should be reduced to half of that recommended in the two Articles, and a continuous arrangement should be used. Because the increased number of structures would increase costs considerably, it is necessary to decide very early in the planning stage what degree of protection is needed on each avalanche control project. It is often possible to get 80 to 90 percent protection for about half the cost of complete protection.

To help decide the necessary degree of protection, each avalanche area can be observed according to the following avalanche-hazard classification:

> Class 1. Frequent avalanche hazard:
Avalanches run once to several times each winter.

> Class 2. Occasional avalanche hazard:
Avalanches occur once each 3 to 6 years. A heavy snowfall on a deep unstable snowpack is usually needed to cause avalanches.

> Class 3. Erratic avalanche hazard:
Avalanches run only under extreme weather conditions, which may not occur for decades -- unusually heavy snowfall or drifting on a highly unstable snowpack.

Along highways, areas in classes 1 and 2 usually require structures; areas in class 3 would not, since it is much cheaper to close the highway when extreme conditions develop than to try to stabilize the area. But if permanent settlements exist in a class 3 area, control is mandatory. Because complete protection is so expensive, avalanches may still occur under catastrophic conditions. Permanent dwellings should be prohibited in any recognizable avalanche-hazard area, regardless of its classification.

7. Design of New Structures

Although designs for structures to control avalanches will change as new materials and equipment become available and as engineers gain experience, the rules and suggestions developed to date will be useful to the engineers who are just entering the avalanche control field. Form, size, and type of structures cannot be standardized because of the variations in snow and terrain conditions, but design criteria essential to any structure are covered in this Manual and in the Guidelines.

The first step is for the avalanche control engineer to gather data on snow depths, snow movement, snow pressures, soil stability, terrain roughness, accessibility, and other pertinent information. From this, design engineers can determine the best size, shape, and type of materials to use, based on the most up-to-date techniques and practices.

The design criteria for supporting structures are usually computed for two types of loading (see fig. 17; also Guidelines, Art. 53). The first, typical of winter conditions when snow depths are great but snow density is low, is based on a maximum snow depth equal to the maximum height of the structure (H). Snow density for Swiss conditions is set at 0.270 t/m^3 (0.27 g/cm^3) for the reference elevation of 1,500 m. on a northerly aspect (see Guidelines, Art. 52). The resultant force is applied at the midpoint of the structure.

The second type of loading is typical of spring conditions after settlement has reduced snow depths and increased snow density. This type of loading is based on a snow depth only 77 percent of the maximum height of the structure (0.77 H). Snow density is increased to 0.400 t/m^3 (0.40 g/cm^3) for an elevation of 1,500 m. and a northerly aspect. The resultant force is applied at 0.385 times the maximum height of the structure (0.385H). In general, structures designed to withstand the heavy loading during spring months (second type of loading) will be strong enough for winter conditions.

Design criteria must also allow for several additional types of loading. One of these is the force created by snow flowing around the ends of structures. This end effect force must be computed for both the first and second types of loading. Another force to be considered is the side load that acts parallel to the contour lines or across the slope. This force acts uniformly over the structure and tends to create lateral instability. A third force which acts parallel to the supporting plane of the structure is called transverse loading. This force can act either up or down and tends to shear the bars of a snow bridge from the trestle.

Guler (1959) illustrates how the numerous forces act on the various parts of open, framed structures, and supplies the details of construction methods in current use.

For design purposes, snow density is adjusted from the reference altitude of 1,500 m. by an altitude factor, f_C. In Switzerland, this factor shows a 2-percent increase for each 100 m. between 1,500 and 3,000 m. (see tabulation, p. 16).

PART III.

THE STANLEY AVALANCHE CONTROL PROJECT -- A CASE STUDY

Part III combines field data on snow cover and terrain conditions with the information in the Guidelines and Parts I and II to develop an avalanche control plan for a specific area -- the Stanley Avalanche.

The Stanley Avalanche starts at 12,400 feet elevation m.s.l., in an alpine bowl about 2 air miles south of Berthoud Pass, Colorado (figs. 26, 27), and extends to Clear Creek, at 9,680 feet m.s.l. The track crosses both limbs of a switchback on U. S. Highway 40. The avalanche runs several times each winter, but does not always cross the highway in both places. Present avalanche control is by artillery fire, which either stabilizes the snow in place or causes it to avalanche.

Previous observations (see Sect. 2.43, p. 20) indicate the best control method would be to use supporting structures in the starting zone with drift-control structures to the windward of the catchment basin. Although an avalanche shed over one or both loops of the highway would be an alternative, the expense of two sheds would be prohibitive; a single shed over the upper road would leave the lower road unprotected because the runout zone is too steep and short for retarding and catching structures.

8. Winter Observations

8.1 Snow Depths

The design of an avalanche control project based on supporting structures requires data on snow depths, measured at the places where the structures are to be built. Field observations of the distribution of snow depths and creep-and-glide measurements were taken in the catchment basin of the Stanley Avalanche during the period of April-June 1962. Snow depths were measured along several profile lines (fig. 28) and were plotted on a map of the area (fig. 29). This type of map should also be used to report the exact location of the fracture lines of slab avalanches. This was not done for the Stanley Avalanche during the 1961-62 winter because detailed maps were not available until August 1962.

The roll of snow on the west rim of the catchment basin is of particular interest. Preliminary investigations revealed that snow depths there are too great to be controlled by normal types of structures. The deep accumulations on this east-facing slope contrast conspicuously with the west-facing one, which was swept bare by the winds all winter.

Two main problems were revealed by the snow conditions in this particular case:

> Can the excessive snow accumulated in the roll be stabilized?
> Does the south-facing slope also receive dangerous masses of snow under exceptional wind conditions?

Both problems should be studied carefully. It might be possible to use some type of snow-drift control together with exceptionally strong and high structures to stabilize the roll. Winter observations should be continued long enough to answer the second question.

Although snow depth and fracture line locations need to be recorded for several more winters to get a comprehensive estimate of winter conditions for the Stanley Avalanche, many years of weather data collected at nearby Berthoud Pass present a good picture of Rocky Mountain weather conditions (Judson 1965).

Figure 26.--Topographic map showing the Stanley and other avalanches along and near U. S. Highway 40 in the vicinity of Berthoud Pass, Colorado. Starting zone of Stanley Avalanche where studies for a structural control project were made is marked with a rectangle.

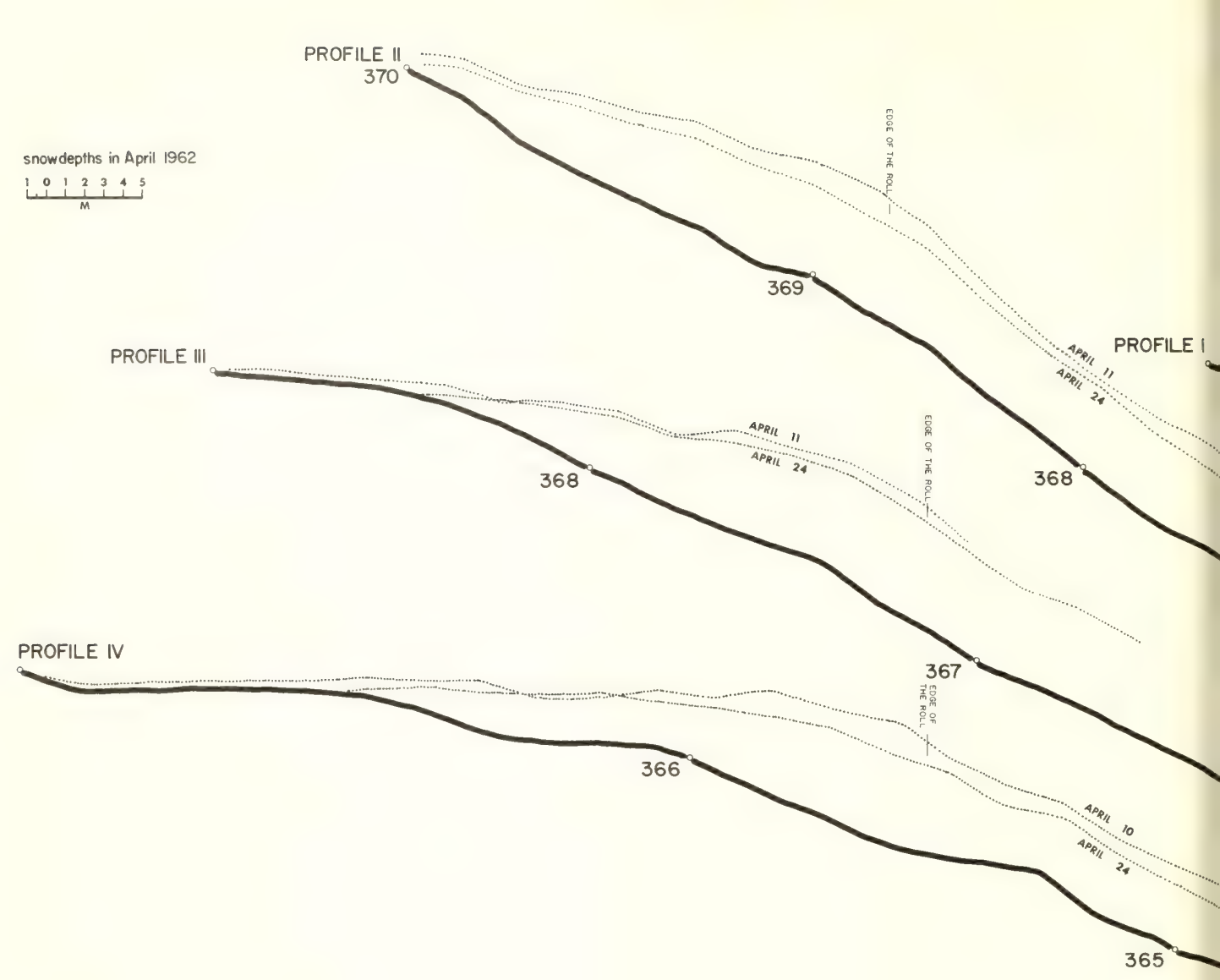
Figure 27.--The path of the Stanley Avalanche, Berthoud Pass, Colorado. This avalanche path crosses the highway in two places. The snow patch in the upper left is the remains of the deep snow roll formed by snow blown from the ridge into the catchment basin. June 18, 1962.

Permanent snow cover starts in late October or early November; snow depths increase linearly from November through February (table 1). Average snow depth by mid-February is 58 inches (1.5 m.). Precipitation increases during March, April, and May. Although maximum snow depth normally occurs April 10-15, it has been recorded as early as March 14 and as late as April 20. The greatest snow depth observed in 13 years of record at the Berthoud Pass study field -- a small opening in the forest one-fourth mile north of the Pass, called Q-12 Park -- was 115 inches (292 cm.) on April 21, 1951 (Judson 1965).

With rising insolation and higher temperatures, the snow cover begins to settle appreciably about the time of maximum snow depth. In this region, highest precipitation is during April and May. Snow depth does not decrease greatly until late May, when the snowpack begins to melt rapidly because of increased insolation and longer periods of clear weather. Rate of snowmelt during late May and early June is 19-20 inches (50 cm.) of snow per week (table 1).

In general, snow depths do not adversely affect structures. Even the extreme of April 1951 with 9 feet (2.7 m.) of snow on the ground is not alarming, because the same winter the extreme snow depth on the study field at Weissfluhjoch, Switzerland (8,000 feet m.s.l.) where there are many structures was 12 feet (3.6 m.). The big difficulty in Colorado is not heavy snowfall; it is the heavy wind transport that alters the deposition pattern of the snow and creates extreme snow depths in local areas.

In terms of structural engineering, any structures built on the Stanley Avalanche would serve the functional purpose of preventing slides for the 5-month period, November-March; they also would have to endure their heaviest loading during April-May when they would be subjected to the enormous pressures in the settling snowpack (see graph with table 1).


PROFILE II
370
369
EDGE OF THE ROLL
APRIL 11
APRIL 24
PROFILE I
368
snowdepths in April 1962
1 0 1 2 3 4 5
M
PROFILE III
APRIL 11
APRIL 24
368
EDGE OF THE ROLL
367
PROFILE IV
366
EDGE OF THE ROLL
APRIL 10
APRIL 24
365

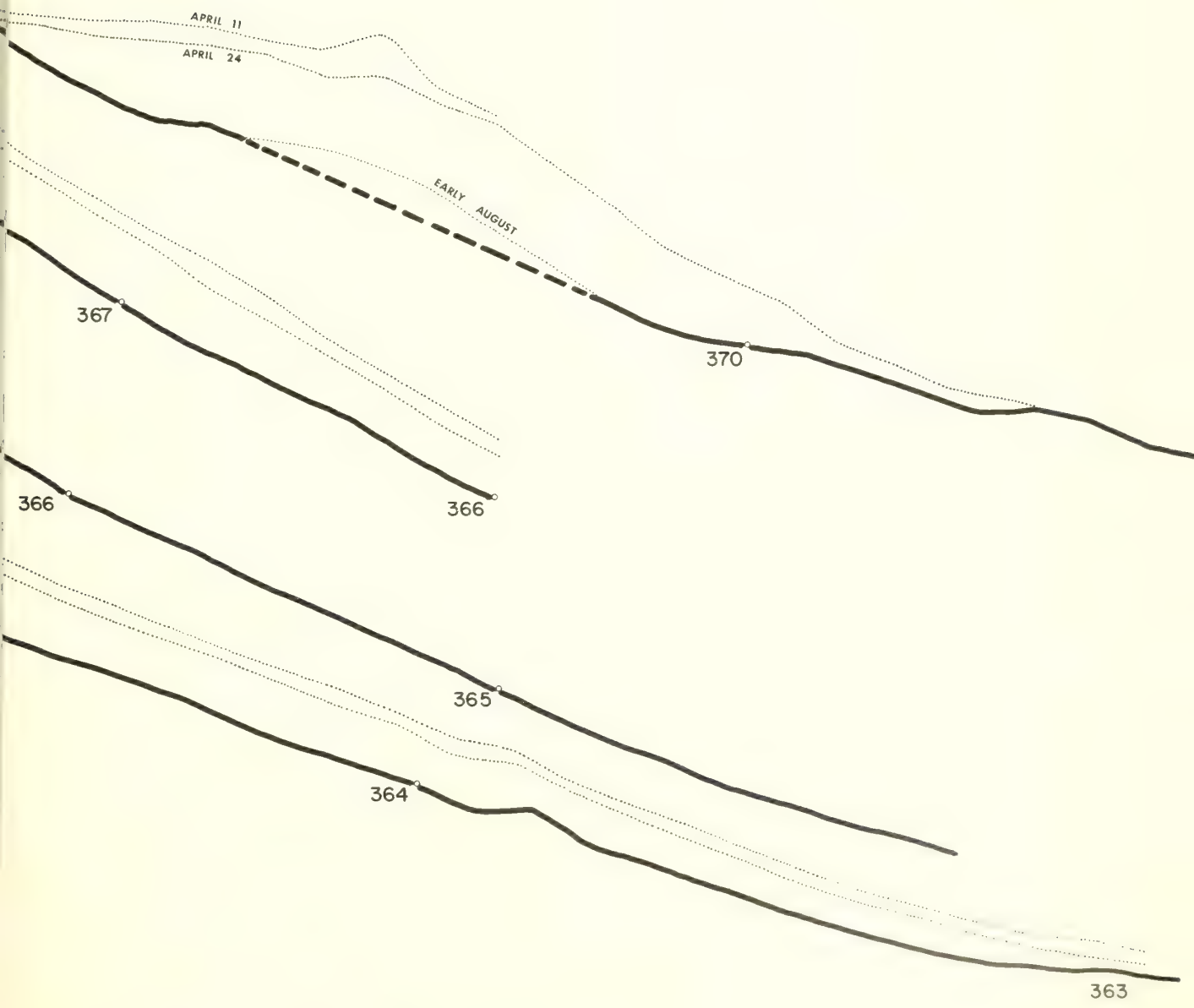


Figure 28.--Four profile lines across the starting zone of the Stanley Avalanche. Snow depths are for April 1962.

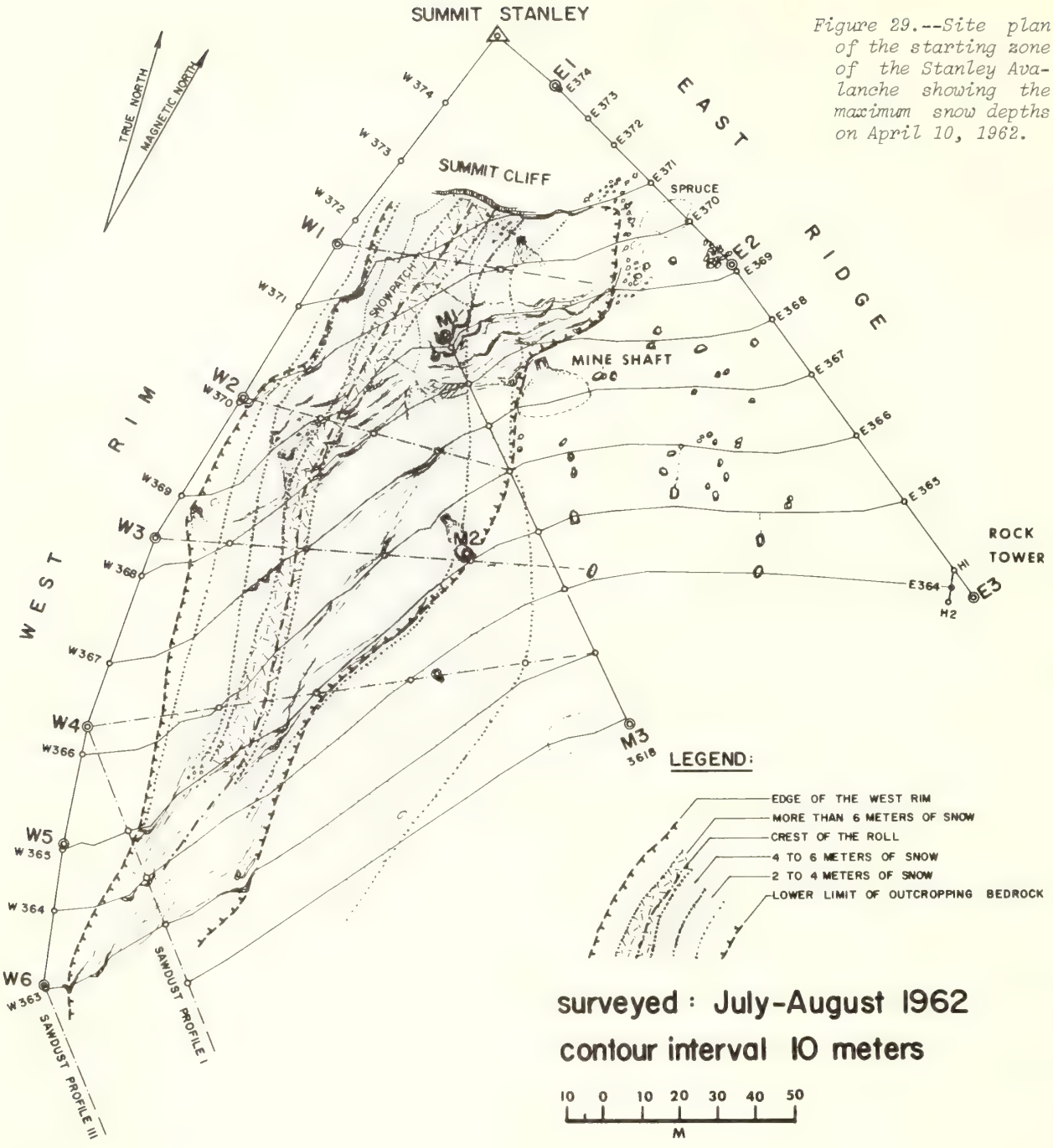


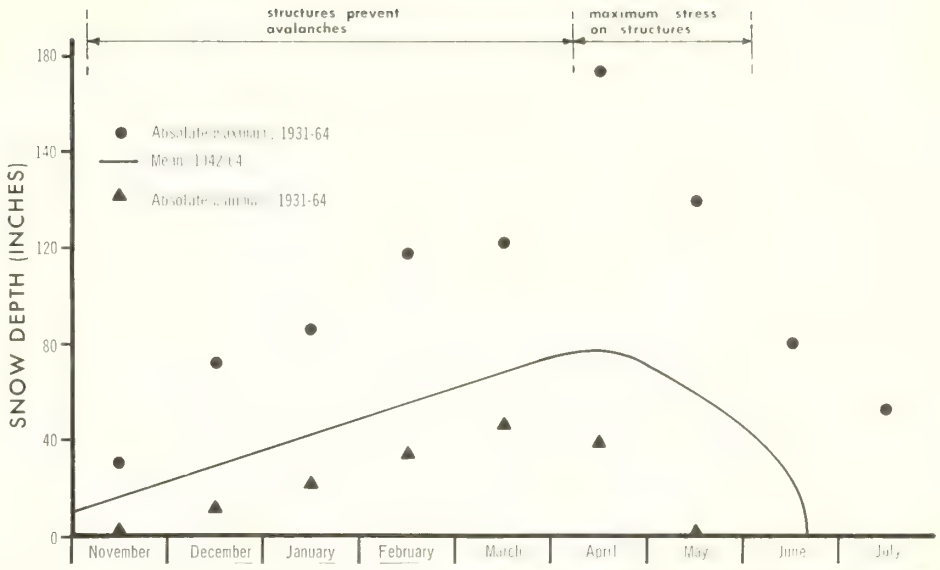
Figure 29.--Site plan of the starting zone of the Stanley Avalanche showing the maximum snow depths on April 10, 1962.

8.2 Creep and Glide

Glide of snow cover is assumed to be of much less significance in the Colorado Rocky Mountains than in the Swiss Alps, because conditions that favor gliding -- warm wet ground covered with long grass -- are not common in the Rockies. Creep is to be expected, however, and must be seriously considered when planning structures because creep due to intense snow settlement causes large pressures.

Some investigations of creep and glide were conducted during the winter of 1961-62 in the catchment basins of the Stanley and Bethel Avalanches in the Berthoud-Loveland Pass area.

Table 1. -- Snow depths[1] at Berthoud Pass, Colorado, taken from daily readings, November-April 1942-64. Graph illustrates depth of snowpack. Structures would prevent avalanches for 5 months (November-March), but would have to endure enormous pressures of settling snowpack (April-May).



Season	November				December				January				February				March				April			
	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum	First	Fifteenth	Minimum	Maximum
	Inches																							
1942-43	--	--	--	--	--	40	--	59	60	53	46	60	59	64	59	69	69	85	69	86	75	42	75	95
1943-44	--	11	5	25	23	24	22	34	38	30	30	43	43	54	43	56	56	55	55	68	68	76	64	94
1944-45	--	6	--	12	12	20	12	24	24	36	24	39	39	49	39	55	54	64	54	74	74	--	54	--
1945-46	10	17	10	26	25	36	26	56	55	54	53	60	55	70	55	75	74	67	65	76	64	66	--	--
1946-47	11	15	11	19	19	29	19	31	31	36	29	36	34	42	34	62	62	59	59	80	80	109	80	110
1947-48	16	11	16	30	30	30	30	34	38	42	38	62	59	57	55	66	66	72	66	84	80	74	68	94
1948-49	6	15	6	21	21	32	21	60	60	51	51	61	58	67	59	70	70	84	79	85	83	85	--	94
1949-50	12	14	4	14	10	14	8	22	16	25	16	43	44	48	43	57	56	58	52	74	77	72	64	82
1950-51	--	--	--	--	--	--	--	--	--	39	--	66	46	76	60	80	73	84	73	92	91	105	--	115
1951-52	--	--	--	24	22	35	22	72	69	55	55	74	70	72	69	87	75	79	75	94	95	90	75	101
1952-53	--	--	--	--	--	21	10	28	28	36	28	48	44	52	44	58	50	55	50	67	65	72	--	72
1953-54	--	--	--	--	--	31	21	38	31	32	29	37	34	35	32	44	44	47	43	60	56	41	--	46
1954-55	--	--	--	--	23	25	22	30	28	34	28	43	42	45	42	58	53	69	49	73	68	69		76
1955-56	--	26	--	28	24	30	24	48	37	47	33	64	59	72	56	74	68	76	63	76	63	79	--	83
1956-57	--	17	11	24	17	31	17	34	30	54	30	56	50	50	48	61	62	65	58	72	66	100	--	108
1957-58	6	18	6	24	23	29	22	46	41	39	36	55	54	63	51	71	62	75	61	80	82	85	80	95
1958-59	--	6	0	19	18	40	18	42	34	39	34	52	52	48	48	75	70	73	68	85	74	77	69	80
1959-60	--	27	--	36	34	33	32	40	38	50	35	54	48	66	48	73	74	93	74	93	87	67	58	87
1960-61	--	13	--	16	16	21	16	34	30	36	29	41	36	38	36	49	48	50	46	60	61	72	58	76
1961-62	21	29	21	33	40	35	33	44	56	63	46	64	67	67	59	77	--	77	67	79	88	86	61	90
1962-63	0	2	0	10	6	11	6	20	17	22	17	36	37	40	37	55	54	53	45	60	48	50	33	52
1963-64	6	5	4	10	8	17	8	31	25	28	23	32	30	37	30	47	44	52	43	67	60	63	49	72
Total	86	252	94	372	371	584	389	827	786	901	713	1128	1060	1212	1047	1412	1281	1484	1213	1681	1605	1744	1267	1972
Mean	10	14	8	22	21	28	19	39	37	41	34	51	48	55	48	64	61	67	60	76	73	77	64	87

[1] Readings December 1942 to April 1951 taken at Bowl behind lodge; November 1951 to April 1964 at Q-12 Park.

Three series of four to six sawdust columns were installed under conditions conducive for maximum creep and glide -- steep slopes, southerly aspects, and deep snow (table 2; fig. 30). Methods used are described here to serve as examples for future studies.

A penetrometer was used to make holes in the snowpack. The lower end of the vertical hole was marked by a wooden peg, which was dropped down the hole and driven into the ground. Experience with the very dense snow in the deep accumulations revealed a need for a better hole-drilling technique. Ice layers within the snowpack very often gave trouble, and it was difficult to mark the

Figure 30.--Photographs show sawdust columns in the Bethel and Stanley Avalanche areas, spring 1962. Drawings show the sawdust profiles, winter 1961-62: A, creep and glide movement of snowpack; B, site plan; and C, longitudinal section of sawdust column series I.

Table 2.--Three series of creep and glide tests, using sawdust columns, installed on southeast slopes at time of greatest snow depth, Stanley and Bethel Avalanches, Berthoud-Loveland Pass areas, Colorado, 1962

Series number, location, and ground-surface characteristics	Slope	Altitude	Columns	Distance between columns	Duration of test	Date of installation	Date pits opened	Data collected
	Percent	Ft. m. s. l.	No.	Feet	No. days			
I. Stanley Avalanche: west roll of catchment basin; rock detritus, fine and coarse material; very little vegetation--only scattered bunches of grass.	60-74	12,000 (3,640 m. u. m.)	6	19.5 (6 m.)	68	Apr. 10	June 17	Columns 3-6 opened; columns 1-2 still had snow depth over 10 feet (3 m.), but snow was melted when checked July 9.
II. Bethel Avalanche: cornice along west rim of catchment basin; outcropping bedrock and rock detritus, mostly coarse material; very little vegetation.	90	12,100 (3,700 m. u. m.)	6	13.0 (4 m.)	65	Apr. 12	June 16	All profiles melted off except column 2 where snow depth was only 26 inches (65 cm.).
III. Stanley Avalanche: same conditions as Series I.	60-74	12,000 (3,640 m. u. m.)	4	19.5 (6 m.)	76	Apr. 24	July 9	All profiles melted off except column 3.

/3

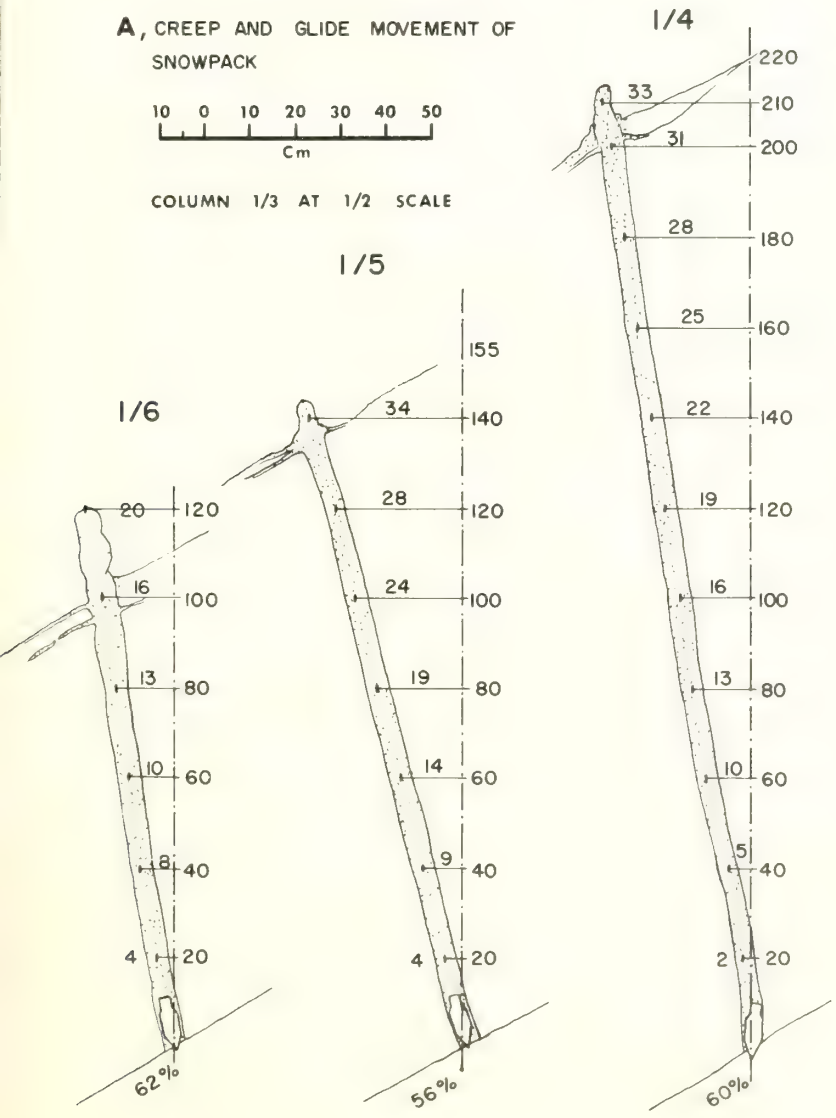
III/3

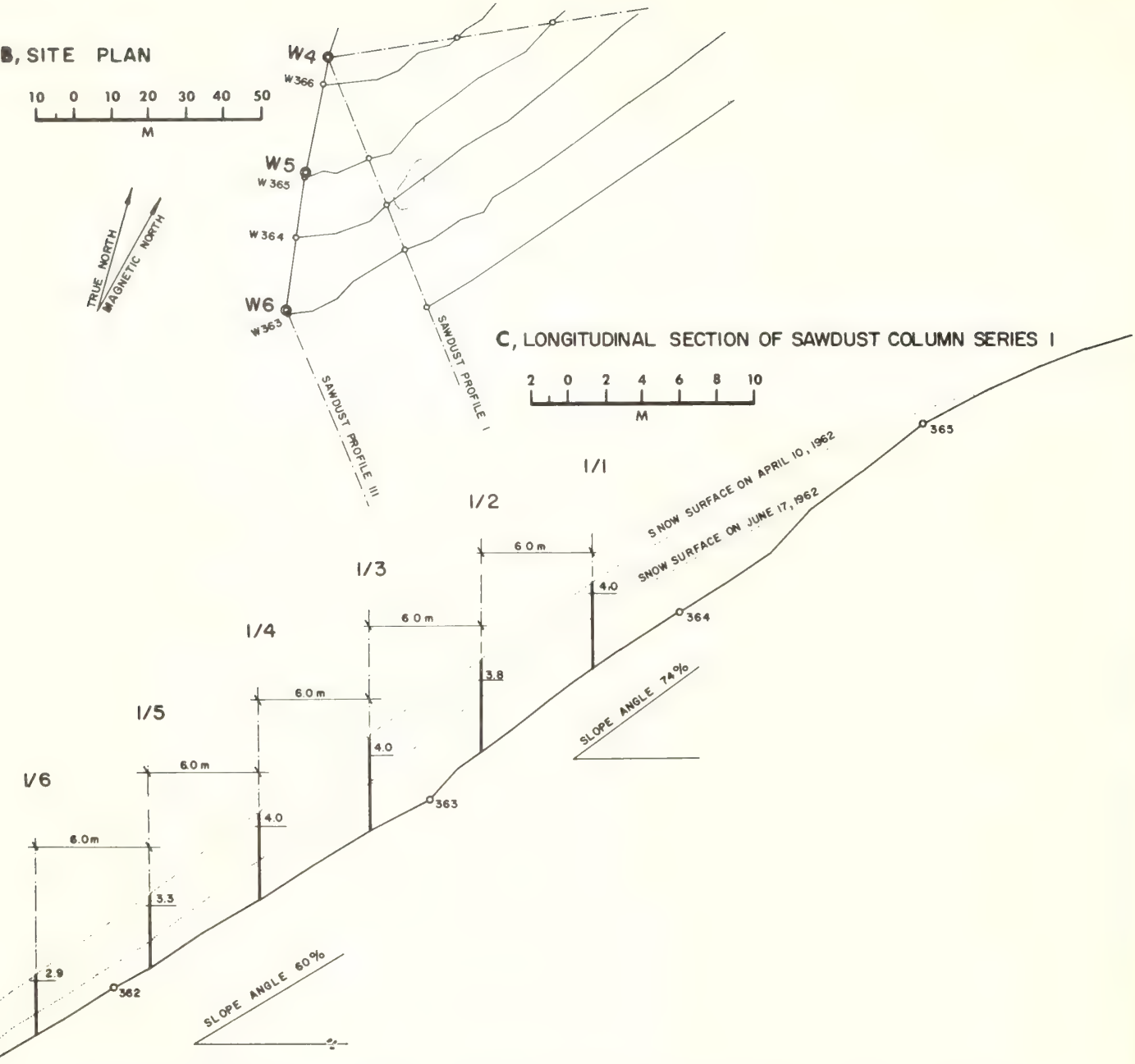
II/2

A, CREEP AND GLIDE MOVEMENT OF SNOWPACK

10 0 10 20 30 40 50
Cm

COLUMN 1/3 AT 1/2 SCALE





lower end of the column because of rocks and boulders on the ground. Perhaps a modified snow sampler with a special cutter would solve the ice-layer problem.

Records were obtained from only 6 of the 16 columns because the others melted out faster than anticipated. The 6 profiles were so similar, however, that it can be assumed with great probability that the other 10 columns would have revealed nothing new. No gliding was found, and the creep showed the usual pattern known from other investigations (Bader et al. 1939, Martinelli 1960).[14] When structures are built in areas where deep snow accumulates, as would be the case in the Stanley and Bethel Avalanche areas, they must be constructed to withstand the large pressures created by snow creep.

[14] *Frutiger, Hans. Eine Winterbeobachtung in der Lawinenbauung "Clünas"/Ftan GR. Int. Bericht 383, 14 August 1961. Eidg. Inst. für Schnee- und Lawinenforschung, Weissfluhjoch/Davos, Switzerland.* [*A winter's observation in the "Clünas" avalanche control project, Ftan GR. Unpublished report 383, Swiss Fed. Inst. for Snow and Avalanche Res.*]

9. Terrain Analysis

The Stanley project area was surveyed in July and August 1962. The site plan (see fig. 29) made from this survey was used to plot snow depths, soil and bedrock conditions, fracture line location, and as a base map for the arrangement of supporting structures.

9.1 General Configuration

The catchment basin of the main part of the Stanley Avalanche is confined on both sides by ridges that are bare year-round because the snow is blown off by high winds. The two lateral profiles marked by survey points W1 to W6 and E1 to E3 follow these ridges. The upper limit of the area is the top of the mountain "Summit Stanley" with a spot elevation of 12,400 feet (3,750 m.) above m.s.l. The lower limit was chosen somewhat arbitrarily following approximately the contour line at 11,900 feet (3,620 m.) m.s.l. It must be emphasized that the catchment basin of the Stanley Avalanche extends to the west of the area shown on the site plan. Here two secondary tracks originate. In addition, there are steep slopes in the main track near timberline. Although not covered in this report, these secondary tracks and the steep slopes in the lower part of the main track also should be controlled.

The total area of the project shown on the site plan is 6.65 acres (2.69 ha.). This area can be subdivided into three distinct parts:

> The very steep and exposed summit cliff above the contour line at 12,200 feet (3,710 m.).
> The southeast slope, west of profile M1 - M3.
> The south slope, east of profile M1 - M3.

Normally there is only a little snow on the summit cliff because it is too steep and exposed. When planning the arrangement of the structures, however, care must be taken to control loose-snow slides and even small slabs that may start in this spot, which is too rugged and steep to be controlled directly. The starting spots of the main Stanley Avalanche lie on the southeast slope between 11,900 and 12,200 feet (3,620 and 3,720 m.) m.s.l. This starting zone covers an area of 4.55 acres (1.84 ha.). The south slope, which is less steep, is normally blown bare by high winds. Additional winter observations will be needed to see if this area has to be controlled for unusual snow deposition patterns.

9.2 Soil and Bedrock Conditions

Conditions are generally favorable for the foundation of the structures. There are two types of bedrock in the project area. The summit cliff is a big dyke of coarse, pinkish granite. There are several secondary veins of the same rock downslope. The remaining bedrock is a darker, fine-grained Pre-Cambrian gneiss or schist. Both types of rock would be good foundation material, but both have fissures that might give some difficulties for rock drilling.

The bedrock is well exposed in the summit cliff and farther downslope in a cliff band following contour lines, 12,070 and 12,100 feet (3,680 and 3,690 m.). Below this cliff band it is only partly visible. The detritus covering the bedrock, however, is shallow -- about 1.6 feet (1/2 m.) deep -- west of the line on the site plan marking the eastern edge of outcropping bedrock and following approximately a line that connects the mine shaft with point M2 and point W6. East of this line the bedrock may be too deep for construction purposes. The whole basin is well drained, and no particular difficulties from water seeps are expected.

10. Types of Structures Recommended for the Stanley Project

The analysis of the snow and terrain conditions (see Sect. 8, 9) show three different areas with regard to structural control possibilities. A different type of structure is recommended for each area. Two of the types, the wall-fence combination and the snow jack,[15] are special adaptations for Rocky Mountain conditions; the third is the heavy-duty snow bridge well known in European avalanche control areas.

10.1 Wall-Fence Combination

Because the steep, rugged summit cliff is very difficult to control, it is suggested that no structures be installed in this area. Instead, very heavy structures able to catch slides falling from the summit cliff should be built just below the cliff. Because of deep snowdrifts just below the summit cliff and in a narrow band along the west rim, such heavy structures have to be planned anyway. The area that shows more than 18 feet (5.5 m.) of snow depth should be controlled by a special type of supporting structure. The combination of a concrete wall (rib wall) with a fence fixed on top is suggested as a possible solution to the problem (fig. 31). This combination could withstand the enormous settling forces expected in the roll, because the vertical supporting plane of the fence minimizes this type of load. The concrete wall would be adequate to withstand the higher pressure forces in the lower portions of the snowpack.

Both the wall and the fence have been used in avalanche control projects. The combination of a fence atop a massive wall, however, is a unique arrangement suggested for snow roll areas where snow depths exceed 18 feet (5.5 m.).

10.2 Snow Bridges

Heavy snow bridges are recommended for areas on the lower part of the southeast slope (west of profile M1 - M3) where snow depths are expected to be between 10 and 16 feet (3-5 m.). The critical height for a steel snow bridge is between 16 and 20 feet (5-6 m.), depending on steepness of the slope at the site. Higher bridges cannot be constructed economically. Therefore, the critical snow depth for this type of structure was set at 18 feet (5.5 m.). In rolls deeper than 18 feet (5.5 m.), the wall-fence combination or another special type of structure should be used.

10.3 Snow Jacks

A special type of structure called the snow jack (fig. 32) is recommended for parts of the slope where bedrock is not within reach and where snow depths do not exceed 10 feet (3 m.); the more expensive conventional supporting structures are not very satisfactory unless they are anchored to bedrock.

The snow jack is a cheap, easy-to-install tripod built of steel angles (fig. 32). The downhill leg supports the two crossed uphill legs. Chain link fencing is attached to the two uphill legs by means of wire rope to form the supporting plane. Normally, several snow jacks would be connected by steel cables to form a continuous line across the slope. The transverse wire rope connectors are firmly anchored beyond the ends of each line of jacks, and the jacks are guyed on the uphill side. The wire rope guys are flexible, and allow the individual jacks to yield a little to snow pressures and, to a certain extent, to follow the movements of the unstable scree or talus. The stiff connection

[15] *Frutiger, Hans. Suggestions for the design of two types of supporting structures to be used for avalanche control. June 1962. (Unpublished report on file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.)*

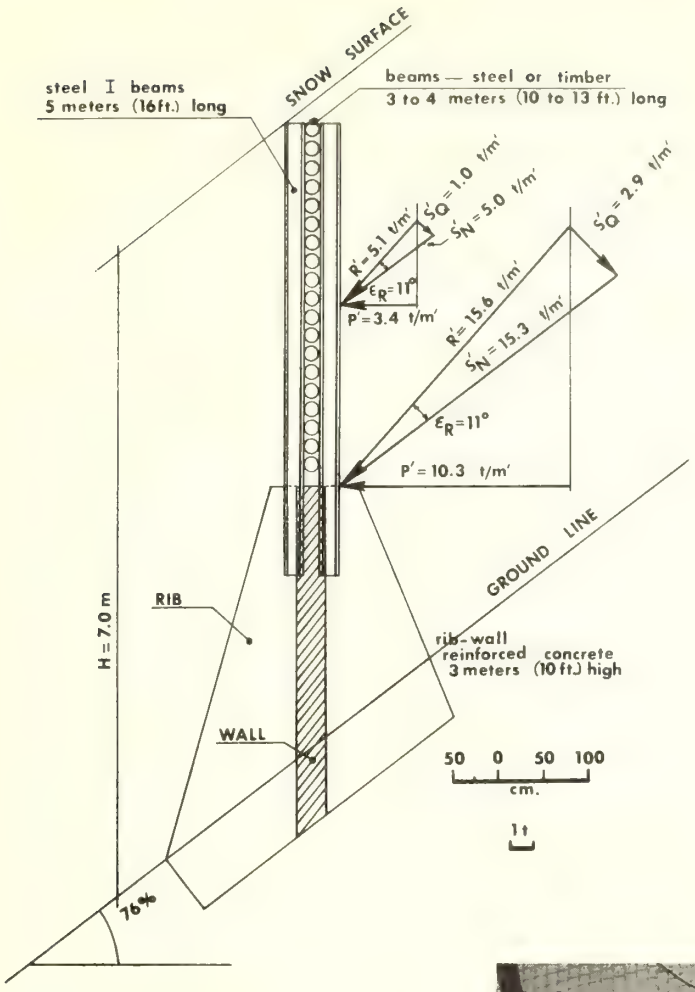


Figure 31.--The rib-wall with a steel fence on top. An especially heavy supporting structure for the control of deep snow accumulation in Stanley Project, Berthoud Pass, Colorado.

Figure 32.--The snow jack, a special supporting structure suggested for areas where bedrock is not within reach and where snow depths do not exceed 10 feet (3 m).

between the two uphill legs and the downhill support plus the flexibility of the whole structure makes it very hard to set up design criteria. Therefore, the dimensions of the members must be chosen somewhat intuitively. As a rough estimate, the snow pressures calculated for a snow bridge can be used.

Snow jacks are recommended for parts of the southeast slope of the Stanley Avalanche, west of profile M1 - M3, where snow depths do not exceed 10 feet (3 m.), and where bedrock is not within reach. Additional data are needed to determine if the south slope east of profile M1 - M3 should be controlled. If control is needed in this area, the snow jack is recommended since snow depths are never great.

10.4 Tests with Snow Drift Controls

Detailed suggestions of how to use drift controls in the Stanley project cannot be made. The deep snow accumulation in the roll raises some problems for control of this zone (see Sect. 8.1). It is obvious that drift control should be tested on the west rim. If it is possible to retain some snow up on the flat ridgetop, there would be less snow in the roll to the lee of the ridge, and the supporting structures would be relieved considerably. Therefore, the project should contain some snow fences, at least for testing purposes.

11. Arrangement of Structures for the Control of the Stanley Avalanche

11.1 Extent of the Area to be Controlled by Structures

Snow and terrain data gathered in preliminary surveys showed the following parts of the Stanley Avalanche area should be controlled:

	Acres	or hectares
> The summit cliff	0.45	0.18
> The southeast steep rim with snow depths over 18 feet (5.5 m.) -- roll	2.18	.88
> The southeast slope with snow depths between 13 and 18 feet (4.0 and 5.5 m.)	1.26	.51
> The southeast slope and west rim with snow depths less than 13 feet (4.0 m.)	1.11	.45
> The south slope, usually bare of snow	1.65	.67

11.2 Types of Structures and Arrangement

The summit cliff (fig. 33) should be controlled by the topmost line of wall-fence structures. This line of structures follows the contour line at 12,170 feet (3,710 m.). These structures will stop sluffs and slides originating in the summit cliffs. Such slides are not expected to be large since the cliffs are too steep and exposed to the wind to accumulate much snow.

The steep rim on which the roll builds up should be controlled by five more lines of the same type of structures. The second line of these structures would be located on top of the cliff band roughly following the contour at 12,105 feet (3,690 m.); the third line near the foot of the cliff band along the contour at 12,070 feet (3,680 m.). Both lines two and three would be about 300 feet (100 m.) long. Lines four to six would be shorter lines designed to control the crest of the roll where there is more than 18 feet (5.5 m.) of snow. These lines should be staggered downslope along the roll.

The lower portion of the southeast slope where 13 to 18 feet (4.0 to 5.5 m.) of snow are expected would be controlled by snow bridges of the European type.[14] This area will take two lines

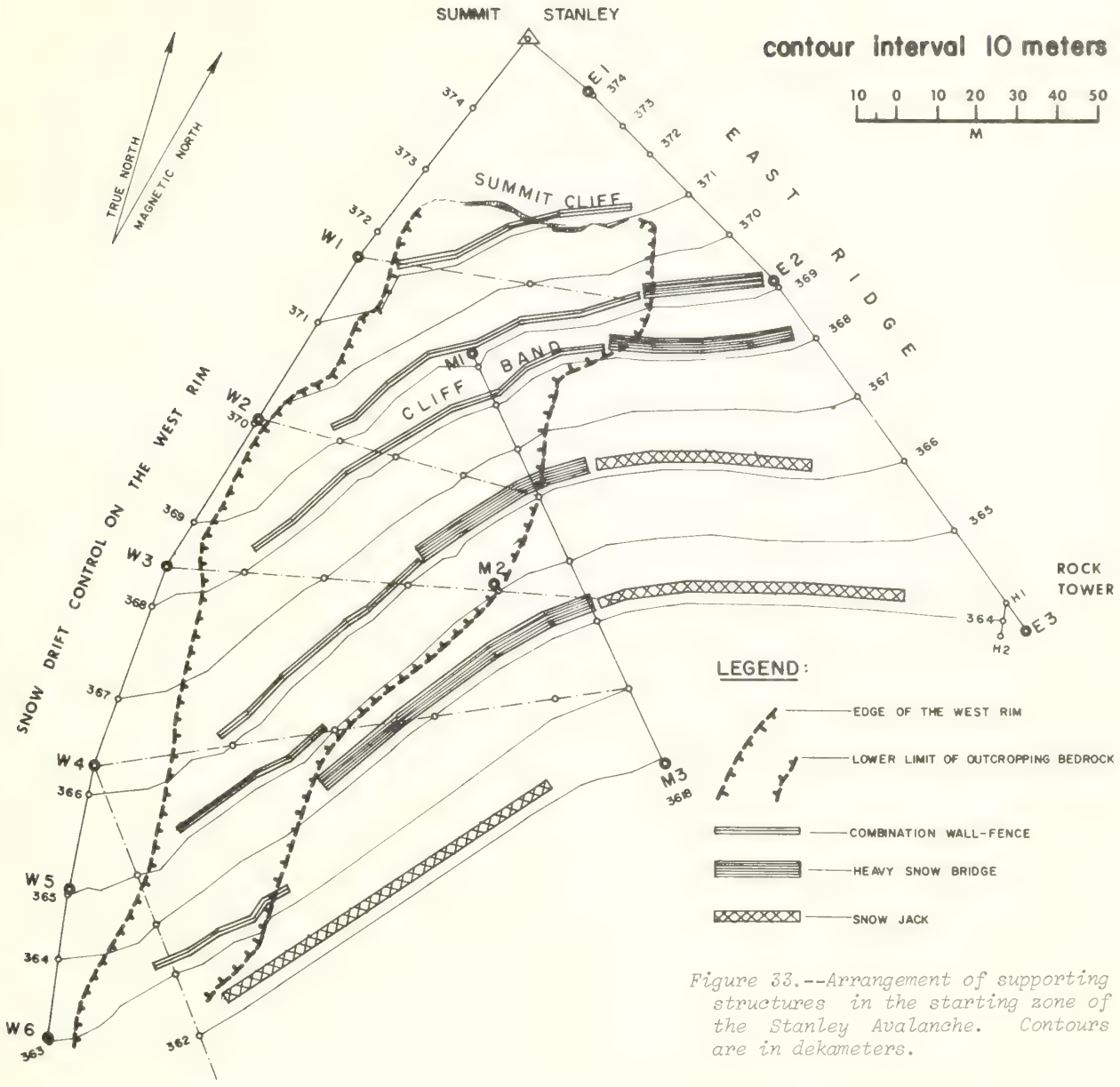


Figure 33.--Arrangement of supporting structures in the starting zone of the Stanley Avalanche. Contours are in dekameters.

of snow bridges, one 165 feet (50 m.) and the other 260 feet (80 m.) long. Below the snow bridges where snow depths are less than 13 feet (4.0 m.), there should be a line of snow jacks about 330 feet (100 m.) long.

The south slope should be controlled at the top by two short lines of snow bridges following the contours at 12,105 and 12,070 feet (3,690 and 3,680 m.). The lines are 100 feet (30 m.) and 130 feet (40 m.) long. As mentioned earlier, there is some question whether control of the lower portion of the south slope is necessary. This report, however, provides for two lines of snow jacks 200 and 260 feet (60 and 80 m.) long until there is definite evidence showing they are not needed.

The continuous arrangement and relatively heavy concentration of snow bridges recommended above have been used in many European areas (fig. 34).

Figure 34.--Closely spaced, continuous lines of supporting structures provide maximum protection from avalanches. These prestressed concrete snow bridges are part of the Kühnihorn Avalanche control project above the village of St. Antönien, Switzerland.

11.3 Distance Between Lines of Structures, and Interval Between Structures

The recommended distance between lines of structures is shorter than it could be according to Guidelines (Art. 20, 21). The southeast slope has a gradient between 60 and 70 percent; 67 percent prevails. According to figure 21 of the Guidelines, the distance would be 180 feet (55 m.) by the formula $L = f_L \cdot H_K$ since f_L for a 70-percent slope is approximately 10 and H_K is 18 feet (5.5 m.). It is unreasonable to put the lines this far apart because of the slides and slabs that are very likely to occur in the steeper portions of the project area. For normal conditions, the distances should not be longer than 100 feet (30 m.), measured along the slope. For complete protection under all conditions, a 70-foot (20 m.) distance probably would be needed.

There are no natural barriers in the project area that would permit a greater interval between adjacent structures and therefore a savings of materials. The uniform slope favors a continuous arrangement. The wall-fence combination and the jacks are arranged continuously. The bridges can be installed with intervals between adjacent structures not exceeding 6 feet (2 m.).

11.4 Total Length of Structures, and Length of Structures Per Unit Area

Figure 33 shows the suggested arrangement of the different types of supporting structures to control the Stanley Avalanche. The total project area is 6.65 acres (2.69 ha.). The area protected by structures is 5 acres (2 ha.). On this area the following structures are suggested:

	Vertical height (Feet or meters)		Total length (Feet or meters)	
Wall-fence combination	23	7.0	1,300	400
Snow bridges	18	5.5	650	200
Snow jacks	13	4.0	800	240
			2,750	840

The length of structures per unit area is 550 feet per acre (420 m. per ha.).

12. Design of Structures for the Stanley Project

12.1 Calculation of the Components of the Snow Pressure Force

The formulas that follow carry the same numbers, in brackets [ ], as those in the Guidelines. Since all formulas have been developed with the metric system, substitutions into them should use that system, then the final result may be converted to U. S. equivalents (feet; inches). For convenience, nomographs 1 through 4 with their related equations have been reproduced separately, and are enclosed in the pocket of the back cover.

12.11 Component Parallel to the Slope (S'_N)

Factors influencing snow pressure and the formula for the component of the snow pressure parallel to the slope, S'_N, are given below (see also Guidelines, Arts. 25, 27, 52). Of course, the validity of this formula for Rocky Mountain conditions must be checked. It is evident that snow conditions in the Swiss Alps differ considerably from those in the Colorado Rockies.

Based on field observations in Colorado and experience elsewhere, the following snow conditions can be used for the Stanley Avalanche:

γ_S - average snow density . . . . . 0.4 t/m^3

H_S - snow depth at the structure site . . 2 to 6 m

K - creep factor [Art. 27]

ψ - slope angle = 76° or 37°

$\sin 2\psi = 0.96$

$K = 0.83 \times 0.96 = 0.8$

N - glide factor $N = 2.4$ [Art. 25,7]

f_C - altitude factor $f_C = 1.3$ [Art. 25,6]

An estimate of S'_N, in tons per running meter, is given by the following formula, which sets the snow depth equal to the maximum height of the structure but assumes a relative low snow density of $\gamma_H = 0.270$ t/m^3.

$$S'_N = 0.10 \cdot H^2 \cdot N \cdot f_C$$ [Art. 52,1]

with the above formula --

for a snow depth of 2 m.: $S'_N = 0.1 \times 2^2 \times 2.4 \times 1.3 = 1.2$ t/m' (805 lbs./ft.)

for a snow depth of 6 m.: $S'_N = 0.1 \times 6^2 \times 2.4 \times 1.3 = 11.2$ t/m' (7,515 lbs./ft.)

Snow bridges with a vertical height of 5.5 m. (18 ft.) will be subject to a snow pressure parallel to the slope of about 10 tons per linear meter (6,710 pounds per foot) during the winter months when the snow is still light.

12.12 Component Perpendicular to the Slope (S'_Q)

The component of the snow pressure perpendicular to the slope is:

$$S'_Q = S'_N \cdot \frac{a}{N \cdot \operatorname{tg} \eta'}$$ [Art. 28,1; 52,2]

where: $N \times \operatorname{tg}\psi = 2.4 \times 0.76 = 1.8$ for a slope of 76% (37°) and a glide factor of 2.4; in the equation, a is a dimensionless number that varies from 0.5 for a light new snow to 0.0 for dense, old, settled snow (table 3).

Table 3. --S'_Q values corresponding to several values of S'_N for two values of a

S'_N			S'_Q if a = 0.35			S'_Q if a = 0.50		
t/m'	or	lb./ft.	t/m'	or	lb./ft.	t/m'	or	lb./ft.
1.2		805	0.2		135	0.3		200
1.5		1,005	.3		200	.4		270
10.0		6,710	1.9		1,275	2.8		1,880
11.2		7,515	2.2		1,475	3.1		2,080
13.8		9,260	2.7		1,810	3.8		2,550

12.13 End Effect Forces (S'_R)

An additional force must be taken into consideration at the free ends of single structures as well as at the free ends of lines of structures. This end effect force, S'_R, is given by the following formula:

$$S'_R = f_R \cdot S'_N$$

[Art. 52,5]

where the end effect factor f_R is given by formula:

$$f_R = (0.92 + 0.65 \cdot N)\,\frac{A}{2} \leqslant (1.00 + 1.25 \cdot N)$$

[Art. 52,6]

with-- A (interval between structures) = 2 m.

$N = 2.4$

$f_R = (0.92 + 0.65 \times 2.4)\,\frac{2}{2} = 2.5$

When f_R is 2.5, the end effect forces, S'_R, for several values of S'_N are:

S'_N			S'_R		
(t/m'	or	lb./ft.)	(t/m'	or	lb./ft.)
1.2		805	3.0		2,015
10.0		6,710	25.0		16,775
13.8		9,260	34.5		23,150

12.2 Application of Calculated Snow Pressures for Types of Structures Suggested

12.21 Wall-Fence Structure

Figures 28 and 29 show maximum snow depths from 1 winter's observation (1961-62). In profile I (fig. 28) more than 33 feet (10 m.) of snow was measured. The other three profiles, however, show maximum snow depth to be only slightly above 20 feet (6 m.). This maximum is reached only in a narrow strip 16 to 33 feet (5 to 10 m.) wide and 650 feet (200 m.) long along the west rim. For this reason it is not necessary to provide a fence high enough to penetrate the maximum snow depth of profile I. A wall-fence with a total height of 23 feet (7 m.) is recommended (see Sect. 10.1).

How strong must this wall-fence be? Formulas for the determination of the snow pressure given in the Guidelines cannot be applied without reservation, since they apply to "a unit length of an infinitely long supporting plane erected perpendicular to the slope ... " (Art. 27,1) and the fence is vertical. The concrete wall (see fig. 31) should be strong enough to support the component of S'_N perpendicular to the structure when S'_N is calculated for a snow depth of 23 feet (7.0 m.). For the steel fence (see fig. 31), this component would be calculated for a snow depth of only 13 feet (4.0 m.). The pertinent factors for the Stanley area are:

Extreme vertical snow depth for wall	$H = 7.0$ m. (23 feet)
Extreme vertical snow depth for fence	$H = 4.0$ m. (13 feet)
Glide factor	$N = 2.4$
Altitude factor	$f_C = 1.3$
Angle of slope	$\psi = 76\%$
Arrangement	Continuous structures

-- FOR A SNOW DEPTH OF 7.0 METERS (23 FEET) --

$$S'_N = 0.10 \times H^2 \times N \times f_C \qquad \text{[Art. 52,1]}$$

$$S'_N = 0.1 \times 7.0^2 \times 2.4 \times 1.3 = 15.3 \text{ t/m'} \qquad (10{,}265 \text{ lbs./ft.})$$

$$S'_Q = S'_N \times \frac{a}{N \times \operatorname{tg}\psi} \qquad \text{[Art. 52,2]}$$

when $a = 0.35$

$$S'_Q = 15.3 \times \frac{0.35}{2.4 \times 0.76} = 2.9 \text{ t/m'} \qquad (1{,}950 \text{ lbs./ft.})$$

Then, if R' is the vector sum of $S'_N + S'_Q$

$$R' = \sqrt{(15.3)^2 + (2.9)^2} = 15.6 \text{ t/m'} \qquad (10{,}470 \text{ lbs./ft.})$$

Now, the tangent of the angle ϵ_R between resultant R', and S'_N can be expressed as

$$\operatorname{tg} \epsilon_R = \frac{S'_Q}{S'_N} = \frac{2.9}{15.3} = 0.1895 \quad \text{and} \quad \epsilon_R = 11° \qquad \text{[Art. 52,3]}$$

-- FOR A SNOW DEPTH OF 4.0 METERS (13 FEET) --

$$S'_N = 0.1 \times 4.0^2 \times 2.4 \times 1.3 = 5.0 \text{ t/m'} \qquad (3{,}355 \text{ lbs./ft.}) \qquad \text{[Art. 52,1]}$$

$$S'_Q \ (a = 0.35) = 5.0 \times \frac{0.35}{2.4 \times 0.76} = 1.0 \text{ t/m'} \qquad (670 \text{ lbs./ft.}) \qquad \text{[Art. 52,2]}$$

$$R' = \sqrt{5.0^2 + 1.0^2} = 5.1 \text{ t/m'} \qquad (3{,}420 \text{ lbs./ft.})$$

$$\operatorname{tg} \epsilon_R = \frac{S'_Q}{S'_N} = \frac{1.0}{5.0} = 0.2000 \quad \text{and} \quad \epsilon_R = 11° \qquad \text{[Art. 52,3]}$$

The load P' per running meter and perpendicular to the fence is determined graphically, in figure 31:

P' (7.0 m.) = 10.3 t/m' (6,910 lbs./ft.)

P' (4.0 m.) = 3.4 t/m' (2,280 lbs./ft.)

12.22 Snow Bridge

The snow bridge commonly used in Europe has a grate with an effective height, D_K, of between 3.0 and 4.0 meters (10 and 13 feet), and a length, l, of 4.0 meters (13 feet). The following factors apply to the Stanley project area:

Extreme vertical snow depth	$H = 5.5$ m. (18 feet)
Extreme thickness of the snow cover	$D = 4.4$ m. (14.5 feet)
Glide factor	$N = 2.4$
Altitude factor	$f_C = 1.3$
Angle of slope	$\psi = 76\%$
Length of structure	$l = 4.0$ m. (13 feet)
Angle between the supporting plane and a plane perpendicular to the slope	$\varrho = 15°$
Interval between single structures	$A = 2.0$ m. (6.5 feet)

12.221 Snow pressure for the first type of loading. --The first type of loading (fig. 35) takes the stability of the whole structure into special consideration. Therefore, the line of action of the resultant of the snow pressure forces is assumed more or less parallel to the slope, with the point of application at half the height of the snowpack.

$$S'_N = 0.10 \times H^2 \times N \times f_C \qquad \text{[Art. 52,1]}$$

$$S'_N = 0.1 \times 5.5^2 \times 2.4 \times 1.3 = 9.4 \text{ t/m'} \qquad (6{,}310 \text{ lbs./ft.})$$

$$S'_Q = S'_N \times \frac{a}{N \operatorname{tg} \psi} \qquad \text{[Art. 52,2]}$$

$$S'_Q \ (a = 0.35) = 9.4 \times \frac{0.35}{2.4 \times 0.76} = 1.8 \text{ t/m'} \qquad (1{,}210 \text{ lbs./ft.})$$

$$S'_Q \ (a = 0.50) = 9.4 \times \frac{0.50}{2.4 \times 0.76} = 2.6 \text{ t/m'} \qquad (1{,}745 \text{ lbs./ft.})$$

The weight of the snow prism adjacent to the sloping grate of the snow bridge is given by:

$$G' = 0.150 \cdot D^2 \cdot \operatorname{tg} \varrho \qquad \text{[Art. 52,4]}$$

$$G' = 0.15 \times 4.4^2 \times 0.268 = 0.8 \text{ t/m'} \qquad (535 \text{ lbs./ft.})$$

The components of G' are given by:

$$G'_N = G' \sin\psi = 0.8 \times 0.60 = 0.5 \text{ t/m'} \qquad (335 \text{ lbs./ft.})$$

and

$$G'_Q = G' \cos\psi = 0.8 \times 0.80 = 0.6 \text{ t/m'} \qquad (405 \text{ lbs./ft.})$$

To calculate the end effects force, S'_R, it is necessary to first compute the end effect factor, f_R, which is expressed as:

$$f_R = (0.92 + 0.65 \times N) \frac{A}{2} \qquad \text{[Art. 52,6]}$$

$$= (0.92 + 0.65 \times 2.4) \frac{2}{2} = 2.5$$

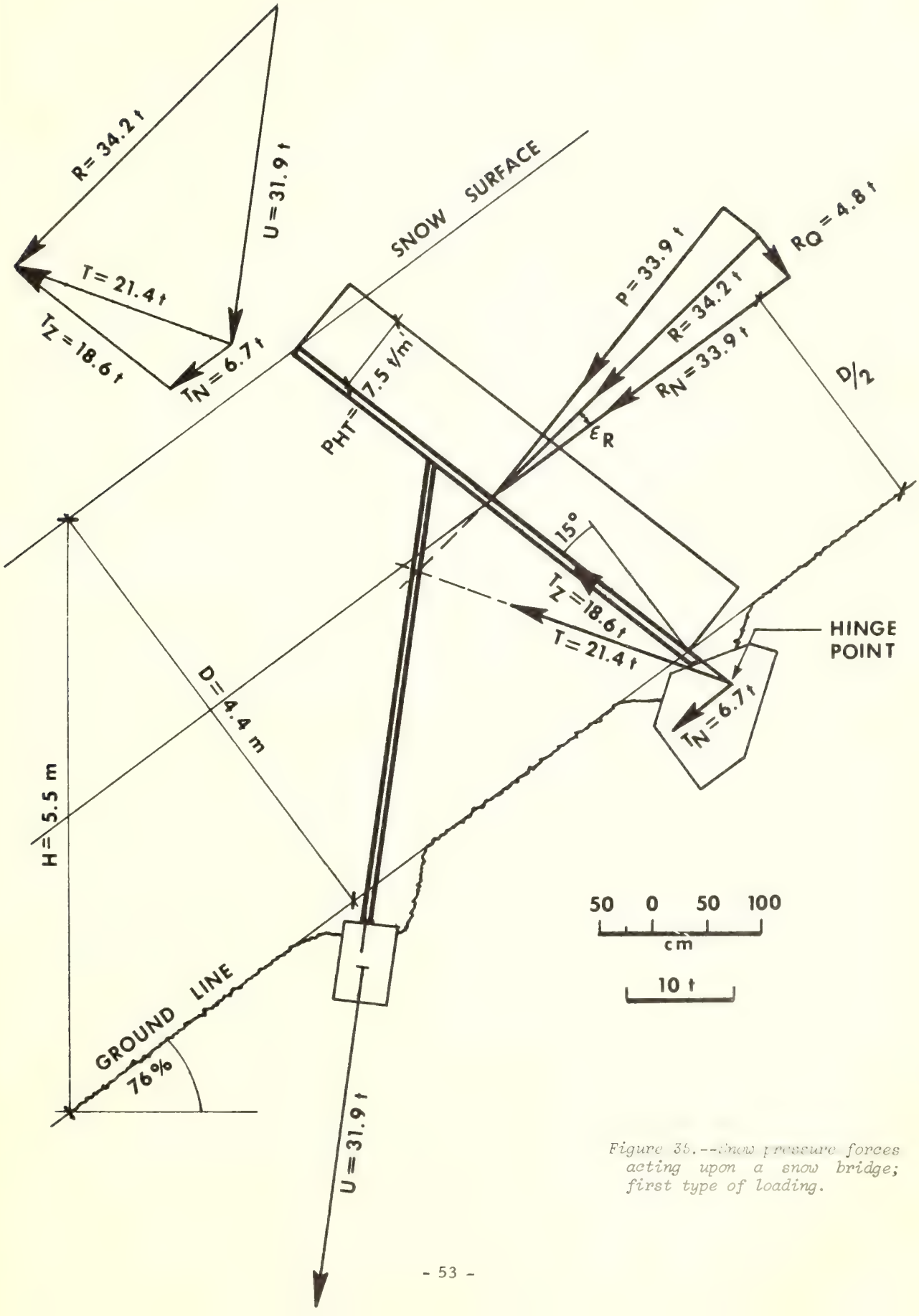


Figure 35.--Snow pressure forces acting upon a snow bridge; first type of loading.

The end effect force is given by:

$S'_R = f_R \times S'_N$ [Art. 52,5]

$S'_R = 2.5 \times 9.4 = 23.5$ t/m' (15,770 lbs./ft.)

The end effect force operates over the length Δl where

$$\Delta l = 0.60 \cdot \frac{A}{2} \leqslant \frac{D}{3}$$ [Art. 52,7]

$\Delta l = 0.60 \times \frac{2}{2} = 0.6$ m. (2 ft.)

The total end effect force parallel to the slope is:

$S_R = S'_R \times \Delta l = 23.5 \times 0.6 = 14.1$ t

Snow pressure forces used for designing the trestle are usually calculated for only half of the bridge length, since the total load on the grate is supported equally by the two trestles. The resultant force parallel to the slope for half of the grate is:

$$R_N = \left(S'_N + G'_N\right) \frac{l}{2} + S_R = (9.4 + 0.5) \frac{4}{2} + 14.1 = 33.9 \text{ t}$$

Generally the trestle is designed for the pressure perpendicular to the slope calculated with a = 0.35.

$$R_Q = \left(S'_Q + G'_Q\right) \frac{l}{2} = (1.8 + 0.6) \frac{4}{2} = 4.8 \text{ t}$$

$$R = \sqrt{R'^2_N + R'^2_Q} = \sqrt{33.9^2 + 4.8^2} = 34.2 \text{ t}$$

$$\text{tg } \epsilon_R = \frac{R'_Q}{R'_N} = \frac{4.8}{33.9} = 0.1416; \quad \epsilon_R = 8°$$

Figure 35 is a diagram of the calculated forces. For the case of separate footings and a support with hinges on both ends, the loadings on the support and the footings can be determined graphically as follows:

Extend the line of action of R until it intersects the support. This intersection and the hinge point in the beam footing give the line of action of T.

Now draw a force diagram as follows: (see upper left corner of fig. 35)

Choose an arbitrary point and draw R to scale and properly alined.
From the same point, draw U of indefinite length but properly alined.
Draw T from the lower end of vector R until it intersects U, using the alinement described above.

Project components T_Z and T_N to the force diagram.

Determine the magnitude of U, T, T_Z, and T_N by scaling the force diagram.

The load on the beam footing is: $U = 31.9$ t

The tension force in the beam footing is: $T = 21.4$ t

with components $T_Z = 18.6$ t and $T_N = 6.7$ t.

The maximum bending moment on the beam at the point where the support is attached can be calculated from the load per unit length of the beam. The load perpendicular to the beam is:

$$P = R \cdot \cos(\varrho - \varepsilon_R) \qquad \text{[Art. 55,1]}$$

$$= 34.2 \times \cos 7° = 33.9 \text{ t}$$

The length of the beam is:

$$B_K = \frac{D}{\cos \varrho} = \frac{4.4}{0.966} = 4.5 \text{ m.} \qquad (15 \text{ feet})$$

and the load per unit length of the beam is:

$$p_{HT} = \frac{P}{B_K} = \frac{33.9}{4.5} = 7.5 \text{ t/m'} \qquad (5{,}035 \text{ lbs./ft.})$$

12.222 Snow pressure for the second type of loading. --The second type of loading (fig. 36) occurs in spring after the snowpack has settled. The decrease in snow depth is accompanied by an increase in snow density. After the snow has settled, the load on the grate is the same as in the first type of loading, but the resultant has a lower point of application and the specific snow pressure is higher.

The entire grate is designed for the specific load caused by the second type of loading, even though the top part of the grate is free of snow in late spring (see Sect. 7). This is done to be sure the grate will be strong enough to absorb the forces caused by possible dynamic loading from sluffs and the very unequal distribution of snow pressure on the grate.

The extra force mentioned in the Guidelines (Art. 55,3) must also be considered. This amounts to 25 percent of the specific snow pressure, p_h, calculated for parts of the grate when there are no end effect forces. This extra force is intended to account for high pressures caused by pronounced gliding when an early snow falls on warm ground and the uneven loading in spring when irregular melting results in the snow receding from all but the lower parts of the grate. The force is active over the whole length of the supporting plane from the ground up to one-quarter of the height.

The loading is determined graphically in figure 36 by the procedure described in Section 12.221. The load on the support and the support footing is $U = 25.6$ t. The tension force in the beam footing is:

$T = 20.8$ t

with components $T_Z = 13.9$ t and $T_N = 12.3$ t.

The load per unit length of the beam for the second type of loading is:

$$p_{hT} = \frac{P}{0.77 \times B_K} = 9.8 \text{ t/m'} \qquad (6{,}575 \text{ lbs./ft.}) \qquad \text{[Art. 55,2]}$$

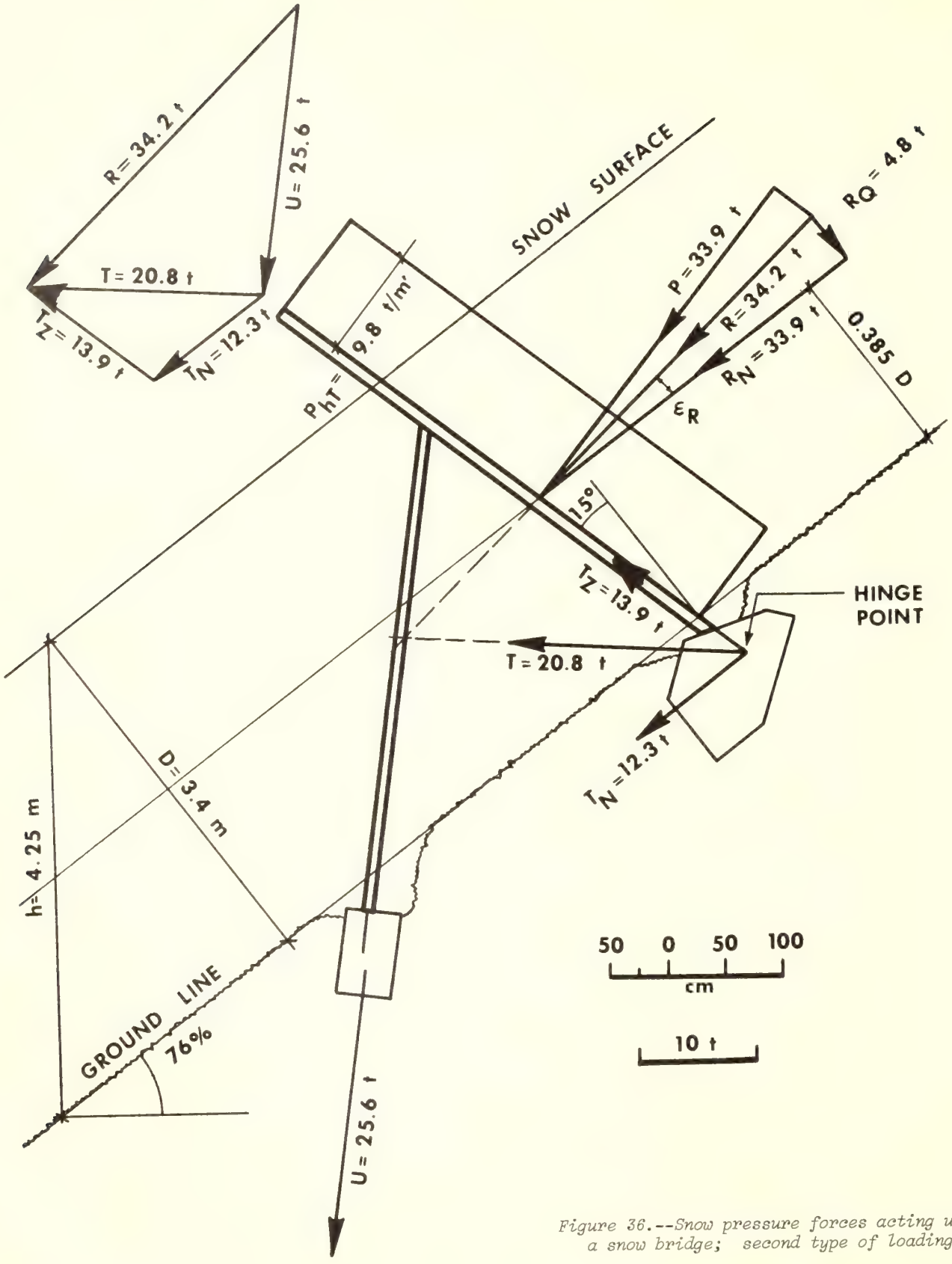


Figure 36.--Snow pressure forces acting upon a snow bridge; second type of loading.

In designing the grate of a snow bridge, two specific loadings, p_h, are calculated:

one for the section of the grate where end-effect forces are acting;

another for the section where there are no end-effect forces (fig. 37).

-- WHEN END-EFFECT FORCES ARE PRESENT --

$R'_N = S'_N + S'_R + G'_N = 9.4 + 23.5 + 0.5 = 33.4$ t/m' (22,410 lbs./ft.)

R'_Q (a = 0.35) $= S'_Q + G'_Q = 1.8 + 0.6 = 2.4$ t/m' (1,610 lbs./ft.)

$R' = \sqrt{33.4^2 + 2.4^2} = 33.5$ t/m' (22,480 lbs./ft.)

$\text{tg } \epsilon_R = \frac{2.4}{33.4} = 0.072; \quad \epsilon_R = 4°$

$P' = R' \times \cos(\varrho - \epsilon_R) = 33.5 \times \cos(15° - 4°) = 32.8$ t/m' (22,010 lbs./ft.) [Art. 55,1]

$p_h = \frac{P'}{0.77 \times B_K} = \frac{32.8}{0.77 \times 4.5} = 9.5$ t/m^2 (1,950 lbs./sq. ft.) [Art. 55,2]

-- WHEN END-EFFECT FORCES ARE ABSENT --

$R'_N = S'_N + G'_N = 9.4 + 0.5 = 9.9$ t/m' (6,645 lbs./ft.)

$R'_Q = S'_Q + G'_Q = 1.8 + 0.6 = 2.4$ t/m' (1,610 lbs./ft.)

$R' = \sqrt{9.9^2 + 2.4^2} = 10.2$ t/m' (6,845 lbs./ft.)

$\text{tg } \epsilon_R = \frac{R'_Q}{R'_N} = \frac{2.4}{9.9} = 0.242; \quad \epsilon_R = 14°$

$P' = R' \times \cos(\varrho - \epsilon_R) = 10.2 \times \cos(15° - 4°) = 10.2$ t/m' (6,845 lbs./ft.) [Art. 55,1]

$p_h = \frac{P'}{0.77 \times B_K} = \frac{10.2}{0.77 \times 4.5} = 2.9$ t/m^2 (595 lbs./sq. ft.) [Art. 55,2]

The extra force mentioned on page 55 and in Guidelines (Art. 55,3) is equal to:

$0.25 \times p_h$ or $0.25 \times 2.9 = 0.7$ t/m^2 (145 lbs./sq. ft.)

The individual bars on the grate should be designed for a transverse loading no smaller than the q_B given in formula 57,4 of the Guidelines. If the transverse loading computed from the procedures outlined in the Guidelines (Art. 57,2 and 57,3) is larger than the minimum value computed with formula 57,4, use the larger loading.

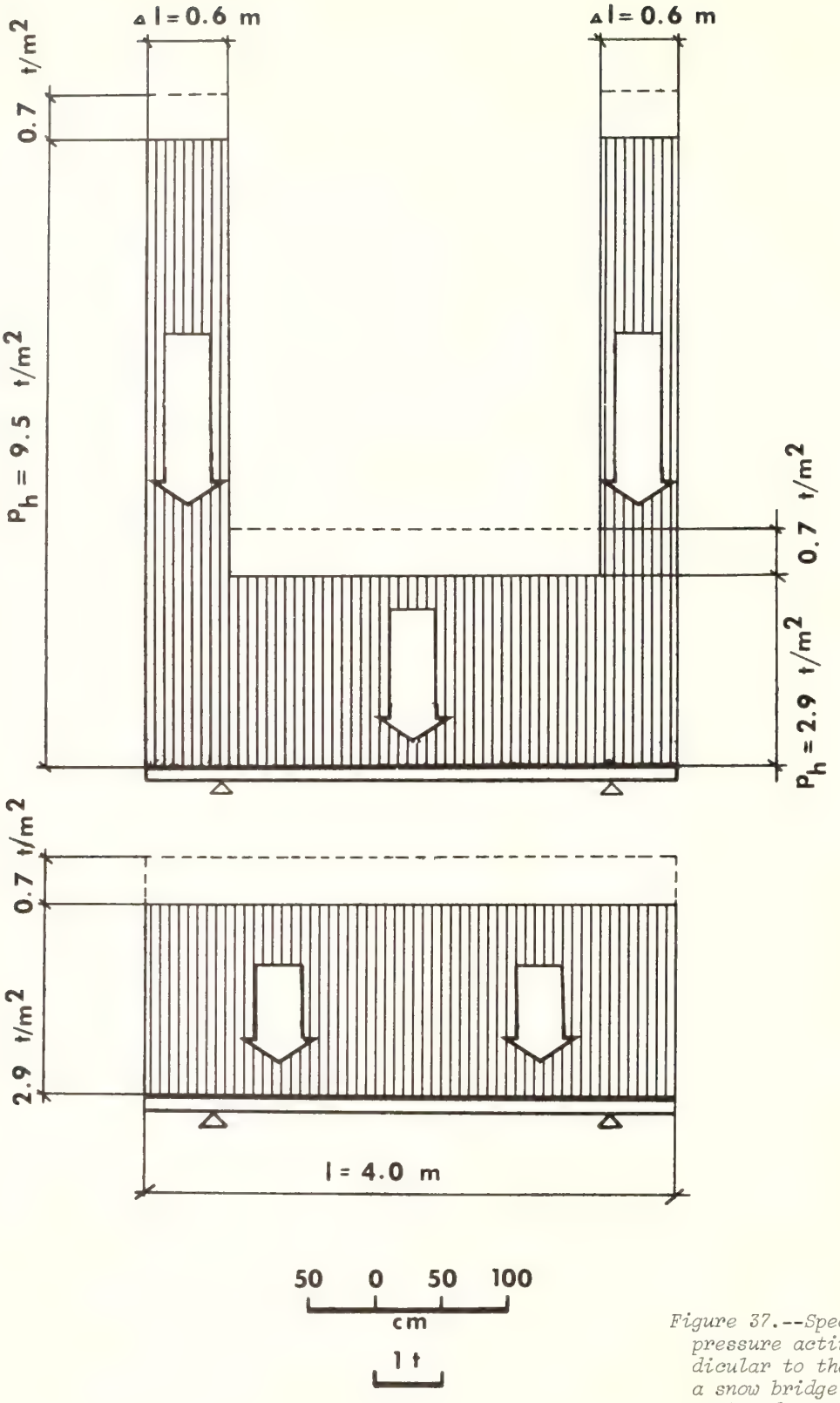


Figure 37.--Specific snow pressure acting perpendicular to the grate of a snow bridge. Above: with end-effect forces; below: without end-effect forces.

-- SECOND TYPE OF LOADING AND END-EFFECT FORCES --

$R'_N = S'_N + S'_R + G'_N = 9.4 + 23.5 + 0.5 = 33.4$ t/m' (22,410 lbs./ft.) [Art. 31,4]

R'_Q (a = 0.50) $= S'_Q + G'_Q = 2.6 + 0.6 = 3.2$ t/m' (2,150 lbs./ft.) [Art. 31,2]

$R' = \sqrt{R'_N{}^2 + R'_Q{}^2} = \sqrt{33.4^2 + 3.2^2} = 33.5$ t/m' (22,480 lbs./ft.) [Art. 31,3]

$\text{tg } \epsilon_R = \frac{R'_Q}{R'_N} = \frac{3.2}{33.4} = 0.096; \quad \epsilon_R = 5.5°$ [Art. 31,5]

$Q = R' \times \sin (\epsilon_R - \varrho)$ [Art. 57,1]

$= 33.5 \times \sin (5.5 - 15)$

$= 33.5 \times 0.165 = 5.5$ t/m' (3,690 lbs./ft.)

$q_h = \frac{Q'}{0.77 \times B_K} = \frac{5.5}{0.77 \times 4.5} = 1.6$ t/m^2 (330 lbs./sq. ft.) [Art. 57,2]

$q_B = q_h \times b$ [Art. 57,3]

letting b = 0.3 m. (1 ft.)

$q_B = 1.6 \times 0.3 = 0.5$ t/m' (335 lbs./ft.)

The minimum load for a bar is:

$q_B = 0.20\, p_B$ where $p_B = p_h \times b$ [Art. 57,4]

$q_B = 0.20\ (9.5)\ (0.3) = 0.6$ t/m' (405 lbs./ft.)

Hence, individual bars of the grate should be designed for a transverse loading of about 0.6 t/m' (405 lbs./ft.)

12.23 Snow Jack

As mentioned in Section 10.3, specific design criteria have not yet been developed for snow jacks. As a first approximation, they should be designed to withstand the snow pressure forces expected on a snow bridge at the site. Further suggestions for the design of snow jacks have been included in an office report.[16]

[16] *See footnote 15, p. 44.*

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APPENDIX

Structures of various types have been used in Europe for at least 300 years to protect highways, railroads, and inhabited areas from avalanches. The use of such structures in the United States and Canada is a fairly recent development. Many costly mistakes can be avoided if full advantage is taken of the experience gained in Europe.

The following articles, translated into English, cover several types of avalanche control structures, and give an insight into current practices in Switzerland and Austria.

The articles by Roch and Schwarz discuss what has been translated as "braking" structures. These are massive structures built on relatively flat places in the avalanche path to slow down and stop moving avalanches. Braking or retarding structures are usually earthen mounds, dams, or walls, but massive prestressed concrete tripods are also used. Both articles emphasize that such structures do not afford complete protection, and that they must be properly located to be effective.

In the third article, Frutiger and de Quervain discuss the relative merits and costs of avalanche sheds versus supporting structures for protecting highways and railways. Although it is not possible to translate the Swiss costs directly into American dollars, the ratio of the two types of control would probably be in the same order of magnitude.

POSSIBILITIES OF PROTECTION BY DEFLECTING OR BRAKING AVALANCHES, OR BY ARTIFICIAL RELEASE

by
A. Roch

(Possibilités de protection en déviant ou en freinant l'avalanche, ou par déclenchement artificiel. In Zum Winterdienst auf Strassen, S. 18-21. Eidg. Inst. für Schnee- und Lawinenforschung, Weissfluhjoch/Davos, Schweitz. Separatdruck aus Strasse und Verkehr, Nr. 1/1964. [In Report of winter road conditions, pp. 18-21, illus. Swiss Fed. Inst. for Snow and Avalanche Res. Reprinted from Streets and Traffic No. 1, 1964.])

Aside from the stabilization of the snow in the fracture zone, the best protection of a road against avalanches is a tunnel or a gallery (avalanche shed). Protection is then complete. But a mountain route all in tunnels is bound to be dull. Moreover, the construction of galleries is very expensive. If there is a possibility to deflect or slow the avalanche in its track, or to release it artificially, these practices will generally be less expensive, but they rarely give complete protection.

We want to study protection systems of this kind and to draw from them the lessons of what to do or not to do.

Deflection of the Avalanche. --To deflect an avalanche in motion is a very delicate operation because the mass of snow can easily pass over the structure destined to deflect it. One is limited, in general, to keeping the avalanche in its track and preventing it from spreading out onto the less steep parts of its course (fig. 17). Numerous walls have been constructed for that purpose in the Alps. In the Bedretto and the Conches Valley and in many villages, there are large walls designed to channel avalanches. At the Valais exit of the Loetschberg tunnel, at two places, large walls prevent an avalanche from spreading out and running over the railroad. These walls are parallel to the direction of flow of the snow.

At Platta Medel on the road to Lukmanier, a wall of prestressed concrete elements has been placed parallel to the direction of flow of an avalanche to protect a forest. That concrete wall was backfilled with dirt on the side opposite the avalanche. Unfortunately, the pillars built on the avalanche side could not resist the creep of the earth [fill]. They slowly leaned downward so much that the cement slabs threatened to pull out of the grooves in the pillars that support them. In order to remedy that fault, the framework of prestressed concrete was used as the back part of a form and a massive concrete wall was poured [against it]. The economy of the prestressed concrete construction was thus lost.

Deflecting walls forming an angle with the direction of the avalanche are rare. Such a wall is now under construction at Fionnay (Valais) to protect a water storage tank. It is sometimes advantageous to channel avalanches with deflection walls to make the snow pass over the roof of a gallery, which can then be shorter. Splitting wedges [tournes en coin] have also been placed on the slopes dominating the approach to a gallery so as to avoid obstructing the entrances.

The Braking and Stopping of Avalanches. --At the bottom of couloirs [gullies], in places where avalanches slow down naturally, large walls at right angles to the track have been built in an attempt to slow avalanches further, or to stop them. These experiments have often been disappointing. At Airolo in 1951, an enormous avalanche passed over a wall and only stopped after damaging 30 homes and killing 10 people. A wall placed at right angles to the direction of travel of an avalanche is not recommended except, for example, when built in a narrow ravine to dissipate the blast of a powder avalanche.

In Austria, the villages of Hötting, St. Niklaus, and Mühlau, in the outskirts of Innsbruck, are periodically menaced by avalanches coming from the mountains dominating the area north of Innsbruck (Innsbrucker Nordkette). The average vertical drop is 1,300 m. The avalanche fracture zones are immense, and each winter more woodland is carried away. Between 300 and 500 m. above the valley, the mountain slopes form a bench with an average inclination of 15°. Engineer W. Hassenteufel took advantage of this configuration to install braking structures. At first, these structures were built of concrete and masonry, backfilled with earth on the downhill side. It was later noticed that simple mounds of earth were sufficiently strong, did the same job, and above all, were less expensive. A number of mounds were placed in that zone. Little by little vegetation covered them and reinforced them. Their efficiency is excellent against avalanches of heavy snow. In fact, the masses of snow stopped on the mounds often increase their height and thus increase their effectiveness. As an experiment, braking mounds were placed on steeper slopes but their efficiency was low.

In Switzerland, the Vobag Company at Adliswil has cast tripods of prestressed concrete designed to resist 40 t/m^2. [These are tripods with two legs parallel to the contours and one leg down the fall line.] Twenty-four such tripods have been placed at Platta Medel above the road to the Lukmanier. Even though they are set very widely apart, their effect is good against ground avalanches of wet snow. In contrast, their effect is almost nil against the blast of powder avalanches. Furthermore, if the snow cover is deep, their effect is much reduced by their pyramidal form. The part that protrudes from the snow diminishes in volume as the depth of the snow cover increases. To remedy these defects, retarding tripods in the form of truncated pyramids with a trapezoidal surface perpendicular to the direction of the avalanche have been built at Andermatt (fig. 18). The facing on their upper side is concrete and they are filled with earth on the downhill side. Their efficiency should be good against powder avalanches too.

We should note again that 10 retarding tripods made by "Vobag" were placed at Fionnay (Valais) to slow an avalanche that threatened a reservoir and some buildings. Six of these tripods were completely broken by an avalanche carrying enormous blocks of rock.

Earthen mounds, as braking structures, were built in Switzerland above Brienzwiler, at a place where there was a terrace on the slope. In 1963, a powder avalanche passed over the mounds. It took out some woodland and stopped not far from the village. It was a close call, but catastrophe had, nevertheless, been avoided. As we mentioned, they do not afford complete protection.

Other mounds have been placed above Amden in the Canton of St. Gall and they have also been installed to protect the Trans-Canada highway [in British Columbia]. Experience shows us that:

Figure 17. Deflecting walls to channelize avalanches in the upper Valais. (Photo A. Roch)

a) Earthen mounds are effective against avalanches of wet snow flowing along the ground. Their effect is very slight against powder avalanches.
b) They must be located only in places where the avalanches are already slowed naturally by a reduction in slope gradient to less than 20°, or 35%.
c) The tripods are effective only if they are sufficiently close together so that the snow deflected from one will hit the next structure immediately. The effect is best if their summits present a reasonable surface area rather than a small triangle, as is the case if their form is pyramidal.

One should be careful in the use of braking structures. Yet, they should not be overlooked for they can mean an enormous savings in comparison to snow support structures in the starting zone and even in comparison to galleries or tunnels. In places where earthen mounds are to retard powder avalanches, an attempt should be made to place dams forming an angle with the direction of the avalanche and aligned so as to deflect the motion of the air and snow, and also to reduce the speed and power by producing turbulence.

Avalanche pits have been installed according to the configuration of the terrain. They are large depressions formed by a ditch on the valley side, depressions into which the avalanche tends to stop. Two such pits have been built on the Arzleralm above Innsbruck. The danger is that these pits can be filled by the first avalanches and the following ones can then pass over them. The dimensions of the depressions must be in proportion to the size of the fracture zone. At Arzleralm, the action of the pits is again reinforced by earthen mounds.

On the Spanish slope of the Pyrenees, enormous masonry barriers have been constructed in avalanche gullies. They are effective in that warm, dry climate.

It has not yet been tried to slow avalanches in a valley by increasing the sinuosity of the avalanche track. This could be done by accentuating the natural projections in the side of the ravine, or by walls along the flanks that would deflect the avalanche.

One could also break the blast of powder avalanches with deflection walls ranged in the middle of gullies, at the places where the blast is strongest. Dams in a ravine could also be very effective. Calculation of the force on these structures is very difficult because these avalanches produce enormous pressures. At Buera Valley in Zuoz, for example, where these measurements have been taken, the forces have exceeded 100 t/m^2.

Artificial Release of Avalanches. --The principle of artificially releasing avalanches with explosives or with gunfire for the protection of roads and communications can be extremely effective in some cases. It is used frequently to render ski trails safe, and on the Bernina Railroad explosives are used to release an avalanche named the "Fat Marianne." The method is practiced at Davos to release the avalanches of the Drusatscha which threaten the railroad as it approaches Davos. After each major snowfall, one to three times each winter, mortar shells are lobbed onto the mountain to try to release the snow. If the avalanche runs, the danger is removed. Usually it is not large enough to go all the way to the railroad, but the mountain is thus relieved of its snow and larger avalanches later in the season are avoided.

Following these practices, there is the risk of provoking a catastrophe like that of Zuoz in 1951. The avalanche which threatens the village, railroad, and highway was released too late by gunfire and carried away four houses and killed six people.

For gunfire to function well, it must be delegated to a local avalanche service, which decides when it should fire, basing judgment on the depth of the new snow, temperature, etc. This method is commonly used for the safety of access roads leading to construction sites in the mountains. It has rendered good service and has avoided accidents. In case of danger, the route is closed. One shoots, then one makes a pass with a snowplow to reestablish the thoroughfare.

In Switzerland, shooting is generally done with an 8.1 cm. mortar. They are distributed by the army which demands certain safety rules. Other means of artificial release utilize explosives, bombs from helicopters, rockets, and shots from bazookas and cannons. In the United States, at Alta and Squaw Valley, recoilless rifles placed on fixed mounts are used.

On the main highways, it is undesirable to stop the traffic to shoot and then to clean up. One would prefer the complete protection of putting the road into galleries or tunnels. But during catastrophic situations, the route will be blocked in any case. It is as well then to shoot in order to protect the road-clearing equipment. At certain spots, avalanches are dangerous only every 20 or 25 years. In these cases, the construction of a gallery cannot be justified; artificial release may then be very useful and will probably prevent catastrophes.

Fig. 11. Structures to [illegible] avalanches at Andermatt.

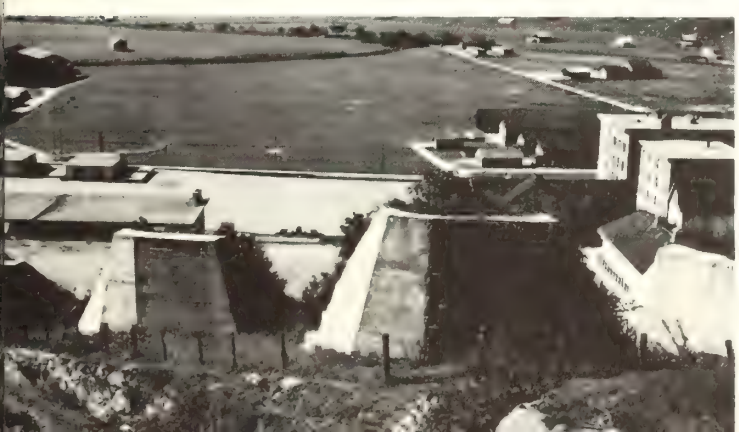
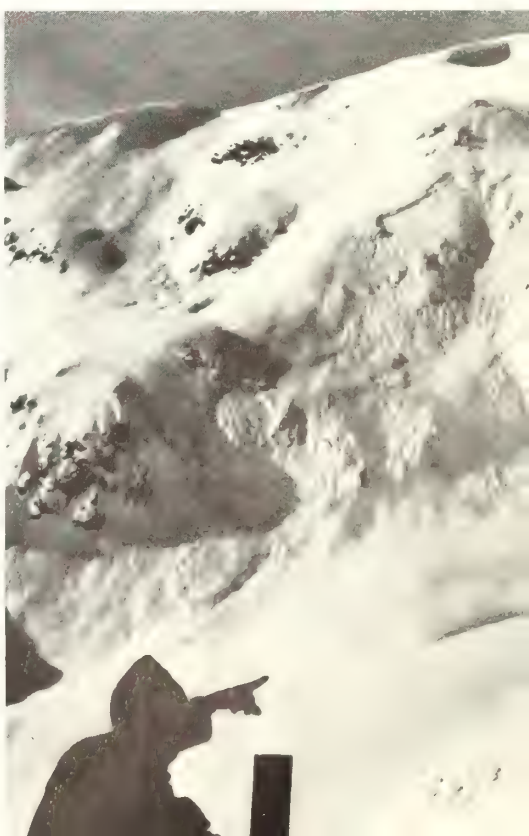


Fig. 12. [illegible] artificially release avalanches.



BRAKING STRUCTURES

by

W. Schwarz, Interlaken

(Bremsverbauungen. Schweiz. Z. Forstwesen, Nr. 1/1960, S. 41-54. [Swiss Forestry Magazine No. 1, 1960, pp. 41-54, illus.])

Structures built in the path of avalanches to "slow down the speed of avalanches and shorten their path through stemming their flow and through frictional action" are called Braking Structures.

According to the glossary of avalanche structures, we distinguish the following braking structures:

Catchdam or catchwall -- a dam or wall at right angles to the avalanche path, built to stop avalanches in the mound area.
Braking mounds -- mounds made of soil or stone.
Braking wedges -- concrete or stone wedge structures.

Catchdams and catchwalls have been built for more than 100 years. The village of Stuben in the Arlberg region has been protected since 1849 by a 6 m high catchwall. However, 5 to 6 m high catchwalls erected at the beginning of the century to protect the village of Airolo on the south slope of the Gotthard, from rockfall proved no protection against avalanches during the disastrous winter of 1950-51. Avalanches swept over these dams into the village, killing 10 persons and destroying 30 buildings.

A more recent practice is the use of mounds and wedges. These developed from the so-called "splitting wedge" concept. Splitting the avalanche into several branches on a field of mounds causes these branches to collide with each other. Furthermore, the snow is so directed that it impacts on the next row of mounds arranged in a checkerboard fashion.

The construction of such obstacles in the path of the avalanche interrupts the normal flow mechanics of the snow. The friction between moving snow and the gliding surface is increased and motion gradually slowed down.

Today the greatest amount of experience with braking structures is found in Austria. On the following pages we will describe some examples of Austrian mound construction.

Mühlau, a suburb of Innsbruck, situated at an elevation of 650 m, has suffered from the Arzlerarm avalanche in 1859, 1923, and heavy damage in 1935. Following the last disaster, eight staggered concrete bulwarks were constructed on a level part of the avalanche path at elevation 1025-1050 m. In addition, two catchbasins with catchdams each 9 m high were erected to collect any avalanches which might penetrate the bulwark field. These catchbasins were constructed at the elevation of 940 m.

Experience with this early construction showed that a similar braking effect could be obtained with earth mounds at a cost saving up to 90%. Two braking fields constructed later on the North chain of the Innsbruck range were made up exclusively of earth mounds. The Penzlehner construction consists of 27 mounds, the Allerheiligen field of 15 mounds. Mounds on the Allerheiligen field have a stone layer (without mortar) on the uphill side of each mound (see figure 2).

Another large Austrian avalanche braking structure made of earth was erected in the 1950's at Heiligenblut (province Kärnten).

Another type of construction must be mentioned here. This construction of Mühlau-Klamm near Innsbruck utilizes the energy-destroying principles used in stream control. Through a series of angled guiding dams and utilization of gullies existing in the avalanche path, it is possible to throw the avalanche alternately from one side to another. To further slow down the avalanche, a system of mounds was added at the bottom of the avalanche path.

Braking construction in Switzerland is of recent date. On the Lasa Alp (Tamina Valley near St. Gallen) seven mounds were built in 1956-57 to supplement existing structures.

At the foot of the Natschen-Grind Mountain near Andermatt, army barracks are protected by a row of eight concrete shell mounds filled with earth.

Braking bulwarks of a different type were erected in 1952 in the Graubünden Canton to protect the villages of Platta-Medels on the Lukmanier highway and in 1957 in Fionnay in the Untervallis.

These so-called "avalanche impact tripods" are made with prestressed concrete beams (made by Vobag in Adlisvil-Zurich) and constructed for a static pressure of 40 t/m^2. These tripods not only deflect avalanches but also cause them to be slowed down due to forcing of the snow between the beams of each tripod (see figure 5).

On the following pages we will describe the early history, planning, and construction of another Swiss braking structure on the Alpögli-Wilerhorn (Brienzwiler community, Bernese Oberland) which was completed in 1958. Avalanches originate on the south slope of the Wilerhorn (2004 m) and after traversing a series of horizontal ledges of 45-50° angle, reach a less steep area at elevation 1440 m on the Alpögli which is partly blocked by a natural barrier.

During the last 50 years several avalanches have broken over this natural barrier and through the protection of the forest, toward the village of Brienzwiler (population 600, elevation 702 m) which is located on the Brunig highway. In February of 1908, an avalanche opened up a 40 to 50 m wide clearing in the Grienwald forest below Alpögli. During the early 1940's, unusually large and dangerous avalanches occurred along the whole Brienzer range. This increase in avalanche activity coincides with the cessation of hay cutting on the slopes. The long stemmed grass, no longer mowed, increased the glide factor materially.

On March 8, 1945, a large avalanche fell on the Wilerhorn and continued on the west side of the 1908 clearing below the Alpogli. It destroyed 4000 m^3 of timber and opened a wide clearing down to the 800 m level. Other avalanches followed in 1946, 1952, 1954, and 1958 causing further damage to the forest stand and to farm sheds.

The danger to the village of Brienzwiler has grown to such an extent that defensive measures had to be planned. The question arose whether to erect barriers in the starting zone or construct a braking system. A barrier system would have to be spread over 4.75 hectares of which 0.75 was timbered. The area was also cut by deep gullies and steep vertical walls. These factors, as well as poor anchoring conditions and rockfall from the weathered peaks, would entail a cost of over 1 million Swiss francs for such a defense system. Only a fraction of this sum would be necessary for extensive braking structures in the Alpögli area. A pure braking field, however, would not have been sufficient in midwinter since the Wilerhorn produces dry powder avalanches at that time. Due to the lack of level ground, an arrangement of mounds in sufficient depth was also impossible. A combination of starting zone defenses and a braking mound system would eliminate the deficiencies of either system by solving the financial problem and overcoming the insufficiency of a pure mound system. At the same time such a combination of the two systems would still afford good protection for the village of Brienzwiler.

Based on the above conclusions, the plan for the defense project Alpögli-Wilerhorn covered an area of 2.2 hectares (of which 0.6 hectare was timbered) which included all slopes below the steep gullies producing dangerous powder avalanches. Through a barrier defense system in the starting zone, overburdening the mound system was avoided.

The cost of the project was as follows:

Reforestation	Fr.	50,250
Mound system		146,400
Barrier construction		478,000
Timber clearing		5,000
Road construction		18,000
Various costs		33,000
Unanticipated costs		59,150
Total	Fr.	790,000

The Alpögli mound system containing 23 mounds and having a total length of 170 m was constructed utilizing existing terrain advantages to the fullest. The catchdam was constructed to raise and lengthen the existing natural barrier and to extend above the steep Alpögli slopes. The existing natural catchbasin on the east side of the braking system was extended to the west side. The excavated material was used to construct the catchdam.

Avalanches are broken up on the mound field above the catchdam. The braking mounds are arranged in a staggered pattern in two rows (see figure 6). Utilizing flat spots on the slope, five additional mounds were erected on the east side of the mound field. The angle of the slope on which the lowest row of mounds stands is only 6-17°. The upper row of mounds is on a 17-26° slope and the uppermost three mounds are on a 26-30° slope. At slope inclinations of 30° we come close to the upper angle of friction for flowing snow which is between 32-38° and, therefore, limits the use of braking mounds. Basically, braking structures in the avalanche path should only be erected on flat transitions. It can be assumed that the upper limit of braking mound efficiency is at 30-35% of slope inclination. None of the Austrian mound fields at Arzleralm, Penzenlehner, and Allerheiligenhof are on slopes above 35%. On the Alpögli the three uppermost mounds are on a 50% slope, but they have been built as an avalanche splitting wedge rather than for braking purposes. After splitting the avalanche, one arm is directed toward the double row of mounds on the west side of the field, the other arm flows toward the flat transition on the east side.

The height of the braking mounds was planned according to the expected snow mass. On the Alpögli, the mounds were constructed with a vertical height H of 5.0 m and the uppermost three mounds with a height of 4.0 m. An increase in the effective [working] height of the mounds was achieved by increasing the height of the mounds coinciding with the decrease of the slope angle.

The pressure of the avalanching snow grows proportionately to the square of the avalanche's speed. It is, therefore, expedient to construct mounds relatively low at the upper level of a field and increase the height of successive mounds.

The arrangement of the mounds as already mentioned is staggered as on a checkerboard. A channeling of avalanches is avoided therefore, by filling of the gaps with successive mounds.

Distance between mounds on the Innsbruck North Range is approximately 15 m from base to base. This distance also approximates the diameter of the mound at its base.

On the Alpögli, the effective working distance was kept much smaller at 5.5 m, which results in a center-to-center distance of 20 m. This denser arrangement of mounds results in a lesser impact force per single mound than in the Austrian construction. This was not only done to increase the efficiency of the mound system, but also because of the lack of space to accommodate the mound system.

The distance between mounds in the direction the avalanche travels should depend on the heights of the mounds, the angle of the mound face, and the slope angle. Mound density depends on the availability of earth on the site. Availability of local material for building of mounds has another advantage. Cuts made on the uphill side of mounds consume additional avalanche energy. Austrian systems take the fill in a semicircle from both sides and from the uphill side of the mound. On the Alpögli field, because of the density of the mounds, fill was taken from the uphill side only. This produced a depression 3 to 7 m wide above each row of mounds. Fill taken from the downslope side of the lowest row of mounds created a catchbasin 15-40 m wide and a catchdam 5-7 m high.

The cone profile for the mounds was chosen with a natural face angle ratio of approximately 4:5. The cone faces were seeded with grass or with low-growing shrubs. The Innsbruck North Range mound system was covered on the uphill side with stones. In Heiligenblut (Kärnten) the total cone face was covered with bricks.

The volume of a mound can be calculated (regardless of cone angle) as a frustrum, with the following formula:

$$V = \frac{h \times a \times b}{3} \times \pi$$

where

h = height of the mound measured vertically to the slope from the base to the tip of the cone,
a = half of the largest base diameter, and
b = half of the smallest base diameter.

Following this formula it was found that the 5 m Alpögli mounds had a volume from 320-580 m^3. This wide spread in volume is due to the variation in slope angle.

Construction of the Alpögli mound system was done with one to three traxcavators which had a shovel capacity of 1.25 to 2.00 m^3. Construction time was 2 months. Five men were steadily used for all grading work on the mounds, the catchdam, and the field edges.

Loose, gravelly on-site material was used for the mounds (9,850 m^3 at Sw. fr. 3.10 per m^3), and for the catchdam (9,100 m^3 at Sw. fr. 2.80 per m^3).

After removal of the humus overburden and terracing of the slope with bulldozers, the excellent permeable material was used directly for the mounds and the dam without any further preparation.

Total cost of the project with approximate earth removal of 19,000 m^3 was 85,000 Swiss francs. This amount includes a 900 m nonpaved approach road, and widening of existing roads to accommodate machinery, as well as other items on the construction site.

This summer, work was begun to install a stone covering on the uphill side of the more exposed mounds. The price for the installation is 12.0 Sw. fr.. per square meter of cone surface. This cost is not included in the above-mentioned total construction bid of 85,000 Sw. fr.

The above discussion on the examples of braking systems both here [in Switzerland] and abroad brings to mind some basic questions regarding avalanche structures which were asked by the late Chief Forester Dr. Hess:

Figure 1. Bulwarks (4 m high) on the Arzleralm. Catchdam is below the braking system.

Figure 2. The Penzlehner mound system with stone facing on the uphill side.

1. Could the objects which are to be protected from avalanches be moved at less cost than it takes to build protective structures?
2. Is there some way by which villages and buildings could be protected directly (with bulwarks or through building on elevated ground)?
3. Would it not be more economical to protect highways and railroads with sheds and tunnels rather than with costly barriers in the starting zone?
4. Would diversion walls or dams be as efficient as structures in the starting zone?

Mound construction can certainly be included in question 4. Possible application of mounds in Switzerland is far greater than could be assumed by the number of mound defenses built so far. Protection against avalanches was too often solved by the standard system of structures in the starting zone. In addition, certain resistance is encountered from the local population which has little faith in the still unknown mound system. Also, building of such systems would require that these people give up some of their precious level and producing land. But these considerations should not lead to the exclusion of mound construction, particularly since such systems are far less expensive than the erection of defense systems in the starting zone.

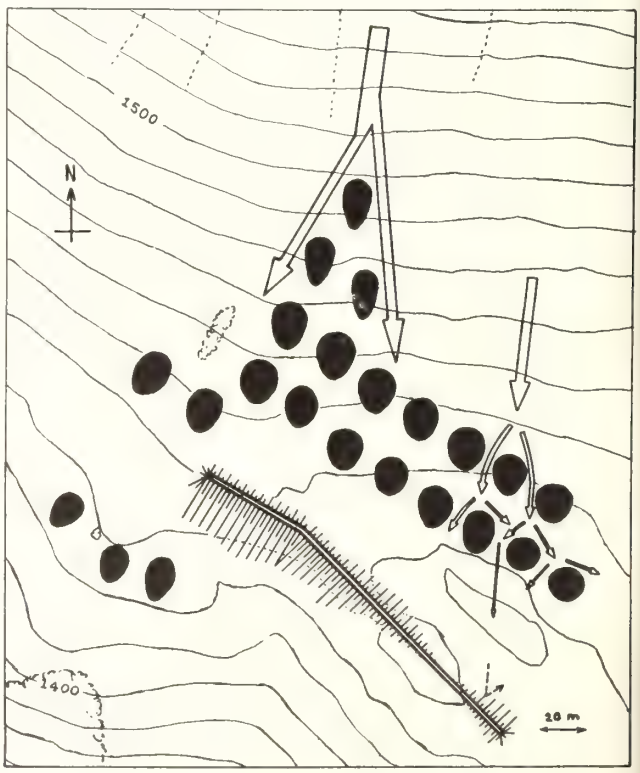


Figure 6. Location sketch of the Alpögli-Wilerhorn braking system.

Figure 5. Avalanche tripods near Fionnay; upper part arranged as a diversion wall.

Figure 4. A combination defense structure of: (2 and 3) guiding dams; (1 and 4) mounds; and (5) a natural barrier, on the Mühlauer-Klamm.

Figure 3. The Allergeiligen mound field with guiding dams to contain avalanches in their normal path.

Figure 7. East side view of the Alpögli defense systems.

Figure 8. Construction mounds with conveyors at Heiligenblut, face angle 1:1.

SUPPORTING STRUCTURES OR GALLERIES?

by

Hans Frutiger and M. de Quervain

(Stutzverbau oder Galerie? In Zum Winterdienst auf Strassen, S. 17-18. Eidg. Inst. für Schnee-und Lawinenforschung, Weissfluhjoch/Davos, Schweitz. Separatdruck aus Strasse und Verkehr, Nr. 1/1964. [In Report of winter road conditions, pp. 17-18, illus. Swiss Fed. Inst. for Snow and Avalanche Res. Reprinted from Streets and Traffic, No. 1, 1964.])

The question of whether to build supporting structures or a gallery (avalanche shed) is usually settled by the cost of the two types of structures. This article then will be an observation and a comparison of the costs of the two systems. Since not many galleries have been built to protect roads, and since most of the gallery building is still in the planning stage, it is difficult to present usable material. To compare the cost of the two systems, the figures from galleries built by the railroad will also be used. In using these figures, one must notice the dates of the expenditures.

According to H. Conrad, the cost of the galleries built in 1949 on the Rhaetian Railroad was 1,440 Swiss francs per running meter. The galleries built by the Austrian Federal Railroads in the years 1954 and 1955 cost 26,000 shillings per meter, which under the rate of exchange of 16.80 costs about 1,550 Swiss francs per running meter. In the years 1954 and 1955, five galleries were built for the protection of the so-called tourist highways. The widths of these galleries were 5.5 meters, increasing to 6.6 meters in the curves. The cost was between 3,890 and 4,600 Swiss francs per running meter.

The widths of the galleries on alpine roads leading to important passes should be from 7.0 to 8.0 meters. They will cost 5,000 Swiss francs per running meter.

The width of third class national roads is at least 8.0 meters and as a rule 9.0 meters. For these roads, it is almost imperative that galleries costing 5,000 Swiss francs per meter be provided. If we make a comparison of the cost of building galleries on the tourist highways, we will have to concede a cost of 5,000 to 8,000 Swiss francs per running meter.

The cost of building supporting structures is listed and discussed elsewhere. In comparing the cost of building these two systems, one has to take into consideration the terrain conditions and the size of the fracture zone of the avalanche in comparison to the length of road to be protected. In the end, however, the deciding factor will be the question of cost.

It will be best to give examples first of situations in which one or the other system will be, without question, the best solution and then to discuss the borderline cases. It is not profitable to build a gallery for small avalanches, in particular those which originate on short, smooth, nonchannelized slopes and which therefore cover a long stretch of road. This type of avalanche brings little snow and also little debris. Often they merely are bank slides which do not offer any particular danger to traffic. If the possibility of afforestation exists, supporting structures will be the more desirable solution.

Other conditions, however, have to be considered. It is possible that in some areas there may be hindrances other than avalanches obstructing a stretch of road, for example, heavy snowdrifts. In this case, the gallery will not only protect the road from avalanches but also from the drifting snow. The gallery will be the best solution for an avalanche whose catchment basin has reached a certain size, but whose track is narrow so that only a short stretch of road is touched by the avalanche. There are, however, limitations here also. It may be possible that a road will cross the same avalanche path several different times which, of course, would necessitate building a gallery at each of these crossings. In this type of situation, as well as in the case of protecting forests or settlements, supporting structures would be the more advantageous or even the only solution.

If the road is located on a steep slope and if the avalanches are channelized, as a rule, the average length of the road which will be in danger of avalanches is from 50 to 70 meters. If, however, the stretch of road is located on a flat area, and in particular if it is located on alluvial fans, the length of road being endangered will be greatly increased. On these cone-shaped runout zones, it is often possible for the avalanche to divide and have damaging side effects and greatly increase the stretch of road which must be protected. Under these unfavorable conditions, galleries have to be more than 100 meters in length. For the purposes of this discussion, we will take 200 meters as the standard length of a gallery.

In order to formulate a comparison, all of the details have to be carefully analyzed. Here is an example in the case of an unconfined avalanche. Let's assume that the cost of building satisfactory supporting structures is 0.6 million Swiss francs per hectare, while the gallery for a main highway costs 5,000 Swiss francs per running meter. For protection against this unconfined avalanche which originates on a short incline, the gallery will be as long as the fracture zone is wide. In order to cover a fracture zone 100 meters wide, it will take a gallery 100 meters long or 0.5 million Swiss francs. The fracture zone can be no more than 80 meters long if supporting structures are to compare favorably in cost with a gallery. If the slope to be built up by supporting structures is longer than 80 meters, the supporting structures will be more expensive than the gallery.

In the case of a large, channelized avalanche, the gallery is undoubtedly more favorable. Assuming a fracture zone of 200 by 200 meters, requiring supporting structures over 4 hectares and a gallery 70 meters long, the comparative cost would be 2.4 million Swiss francs to 0.35 million Swiss francs, or 7 to 1. In this case, only when the length of the gallery is 480 meters or more would the supporting structures become more favorable. The cost of the two systems again compares favorably in a situation where it is necessary to build supporting structures over 2 hectares and a gallery length of 200 meters.

Other things, not necessarily of a financial nature, must also be taken into consideration when deciding which of these two systems to build. Supporting structures are more favorable when they can serve other purposes besides the protection of a road; for example, protection of settlements and forest industries, et cetera. Maintenance cost of supporting structures is fairly high; a gallery, on the other hand, requires relatively little maintenance. One disadvantage of the gallery could be a reduction of travel comfort in summer.

Finally, it is still maintained that the decision whether to build supporting structures or a gallery can only be decided and handled as individual problems depending on the specific circumstances.

[Translator's note: The break-even point seems to be about 100 meters of gallery per hectare of supporting structures, or 130 feet of gallery per acre of supporting structures. The official rate of exchange is about 4 Swiss francs per dollar. A direct translation of costs is not possible, however, because of differences in construction and labor costs.]

Agriculture --- CSU, Ft. Collins

Frutiger, Hans, and Martinelli, M. Jr.
1966. A manual for planning structural control of avalanches. U. S. Forest Serv. Res. Paper RM-19, 68 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Classifies avalanches for avalanche control work. Identifies the important parts of an avalanche area. Discusses the following types of avalanche control structures: Supporting structures and wind baffles in the starting zone; diverting, guiding, retarding, and catching structures in the track; and direct-protection structures in the runout zone. Outlines the field observations and design specifications necessary for planning an avalanche control project, and develops a control plan for a specific avalanche.

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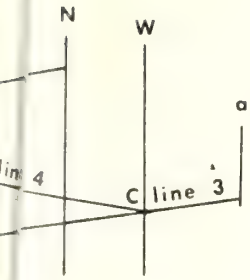

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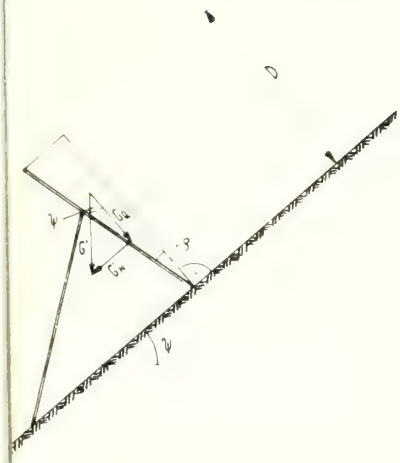

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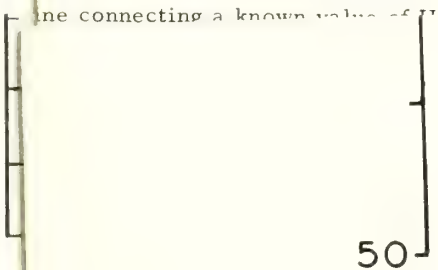

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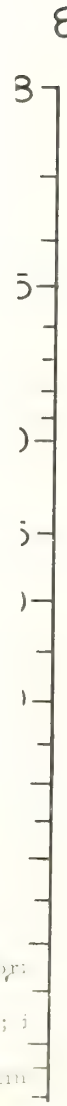

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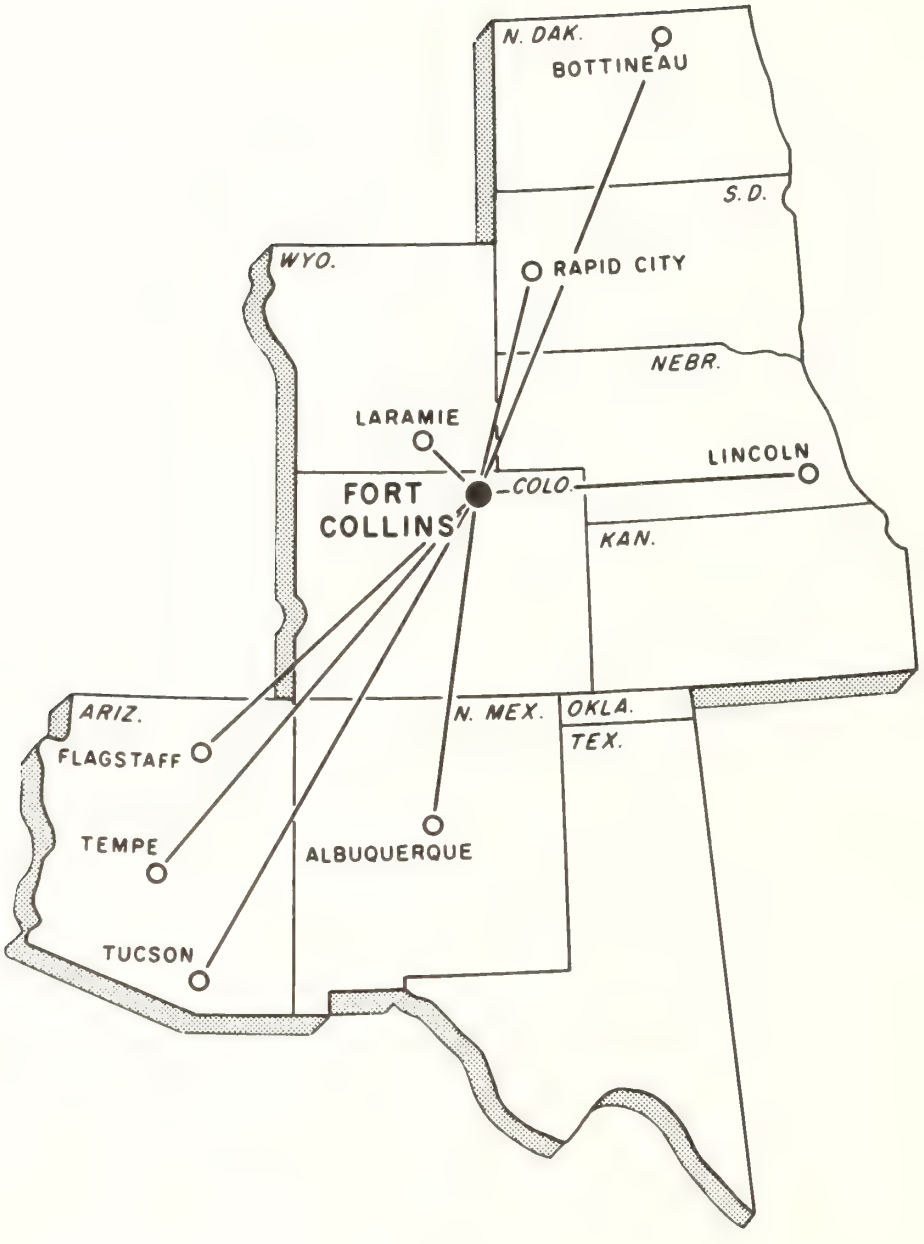
NOMOGRAPH 4

Figure 41 (NOMOGRAPH 4).--Determination of the angle between the resultant R' and the direction parallel to the slope.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May 1966

U.S. Forest Service
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DESIGN, CONSTRUCTION AND COST OF ROCK CHECK DAMS

by Burchard H. Heede

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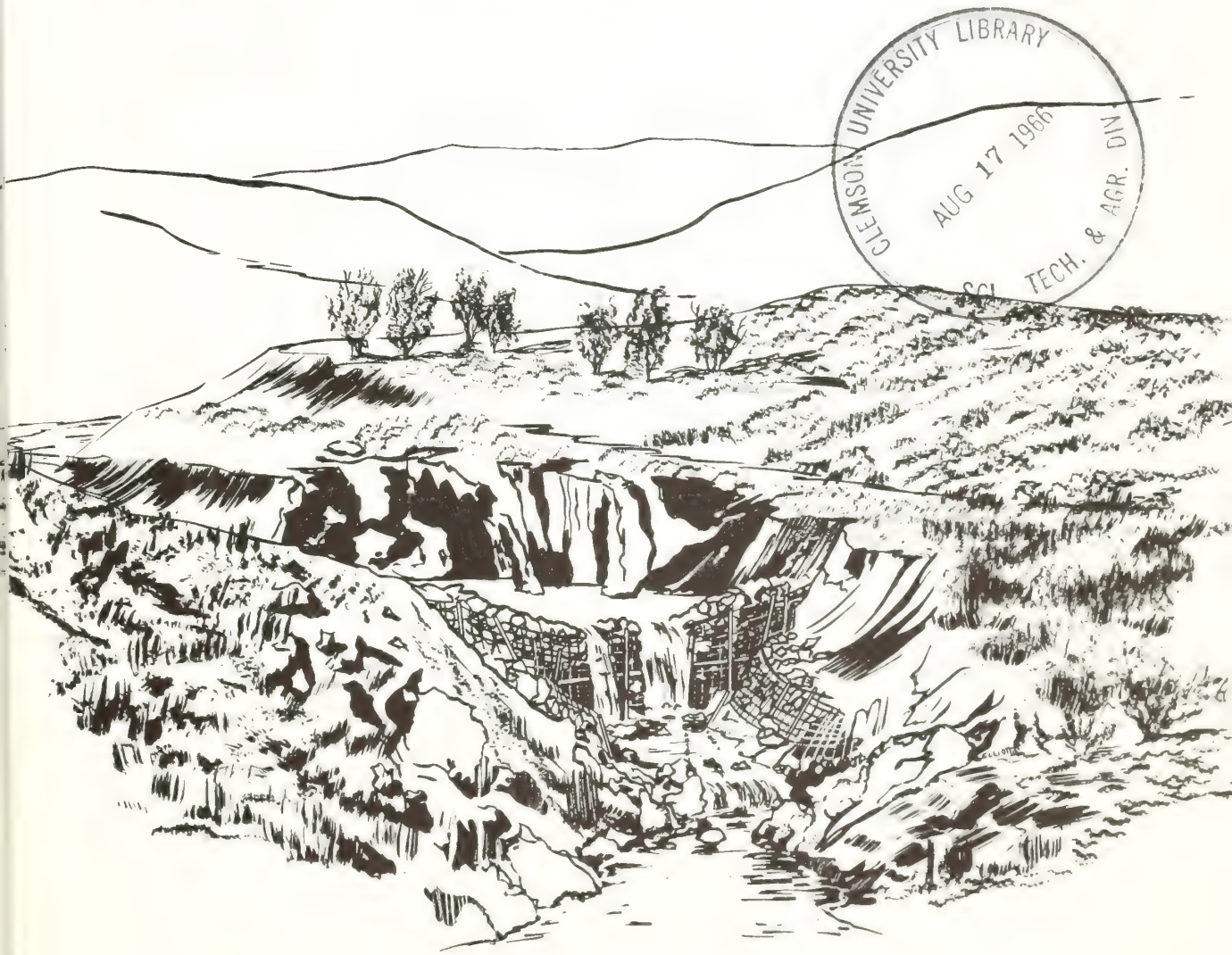

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U. S. Forest Service Research Paper RM-20 May 1966

DESIGN, CONSTRUCTION, AND COST OF ROCK CHECK DAMS

by

Burchard H. Heede, Hydraulic Engineer

Rocky Mountain Forest and Range Experiment Station[1]

[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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Design, Construction, and Cost of Rock Check Dams[2]

by

Burchard H. Heede

Check dams built from loose rock have been used to control the flow of water in gullies and canals since ancient times. Rock remained the principal construction material during the last large-scale installation of check dams in the 1930's when the Civilian Conservation Corps rehabilitated depleted lands. After this period, steel sheets and concrete were the primary materials used in check dams. Although costs of steel or concrete check dams are much higher than those built from loose rock, the use of rock was neglected.

Perfection of modern construction materials was not the only reason for the neglect of rock. Rock check dams, as conventionally constructed, require large amounts of hand labor. New construction methods were not developed to save manual work by application of modern equipment. Also, older rock check dams failed frequently because they were often inadequately designed, placed at unsuitable locations, or not maintained.

The failure to use rock check dams and to improve their design was not justified. Based on studies of 25-year-old structures, Heede (1960)[3] demonstrated that rock check dams can effectively control gullies, and that these structures are long lasting if the conditions of flow and channel are considered in their design and placement. Figures 1 and 2 show a successful rock check dam constructed during our present study. That rock check dams can be effective for more than 40 years is demonstrated by structures in California (fig. 3).

To learn more about the feasibility of using modern techniques in the design and construction of rock check dams, a study was set up with the following objectives:

1. Design and install four different types of rock check dams: double-fence, single-fence, wire-bound, and rock only.
2. Design and construct gully head-cut controls consisting of rock only.
3. Test the feasibility of using conventional construction equipment in the installation of the structures.
4. Determine the costs of the different types of structures and their cost relationships.

Figure 1.--A double-fence rock check dam during the first heavy flow of spring snowmelt. Suspended-sediment concentrations of 35,000 p.p.m. were sampled below this dam.

The work reported here was conducted in cooperation with the White River National Forest, Glenwood Springs, Colorado, and Region 2 Office of the U. S. Forest Service, Denver.

[3]Names and dates in parentheses refer to Literature Cited, p. 24.

Figure 2.--The dam of figure 1 after the snowmelt season. The catchment basin of the dam is filled with sediment to the crest of the spillway, and vegetation is invading the deposits.

Study Area

The structures to be tested were installed on the upper Alkali Creek watershed, tributary to the Colorado River in Colorado. The watershed, about 1 square mile in size, is located on the Rifle Ranger District of the White River National Forest, about 20 miles south of the town of Silt. The elevation ranges from 7,500 to about 8,500 feet. Marine shales and sandstones of the Wasatch formation provide the main parent materials for the soils. Silt and clay contents of the soils are high, about 38 and 50 percent, respectively. The vegetation consists mainly of Gambel oak, big sagebrush, Kentucky bluegrass, and western wheatgrass. Sagebrush grows predominantly on the bottom lands and the south slopes. Gambel oak occupies ridges and the north slopes.

Numerous gullies of varying sizes dissect the bottom and the side slopes of the watershed. Gully flow is ephemeral, and occurs only during spring snowmelt and at times of exceptionally intense summer storms. The load of these flows consists mainly of fines and sand; gravel and boulders are only occasionally transported. A suspended-sediment concentration of 35,700 p.p.m. was sampled at a discharge of 7 c.f.s. during the snowmelt season. This concentration corresponds to a sediment discharge of 16 pounds per second, or about 10 cubic feet per minute.

Figure 3.--Looking upstream on two loose rock check dams, representing hand-placed dry masonry walls, that controlled this tributary gully to Haines Canyon, San Gabriel Mountains, very effectively for more than 40 years. Grass formed thick sod covers on the sediment deposits, adding stability to the structures and the gully.

Records from 1961 through 1965 indicate that the area received an average total precipitation per water year (October 1 to September 30) of 18.57 inches. Judged on the basis of longer records from weather stations, and considering the elevation difference to these stations, this amount appears to be somewhat above normal. Of the total precipitation, 57 percent was snow and 43 percent rain. As illustrated below, several cloudburst storms hit the study area during the period of record:

	Maximum intensity		Total precipitation
	(Inches/hr)	(Minutes)	(Inches)
1963:			
7/9	1.28	15	0.51
7/15	1.80	3	.19
7/23	1.66	21	.60
9/20	1.50	12	.42
1964:			
7/30	1.00	9	.27
8/12	1.90	6	.54
8/12,13	1.20	5	.74
8/27	3.00	1	.38
1965:			
7/31	.96	5	.28
9/2	2.20	3	.29
9/2	3.00	2	.10
9/5	4.20	1	.33
9/11	1.50	10	.47
9/29	4.80	1	.61

The structures did not receive the most severe test during the flows from cloudbursts, but during flows from snowmelt because the melt flows lasted over long periods of time. In the spring of 1964, the melt water ran for 7 weeks continuously in the gullies, and the water saturated gully side slopes and bottoms as well as the foundations of the dams. Furthermore, since recession flows of prolonged melt seasons decrease their load with time, as observed on the study area,[4] check dams are endangered by the increased capability of the water to cause erosion at the structural sites.

[4] *Heede, Burchard H. Suspended sediment of gully flows related to duration of flow. 4 pp. 1964. (Unpublished office report on file at Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo.)*

Methods

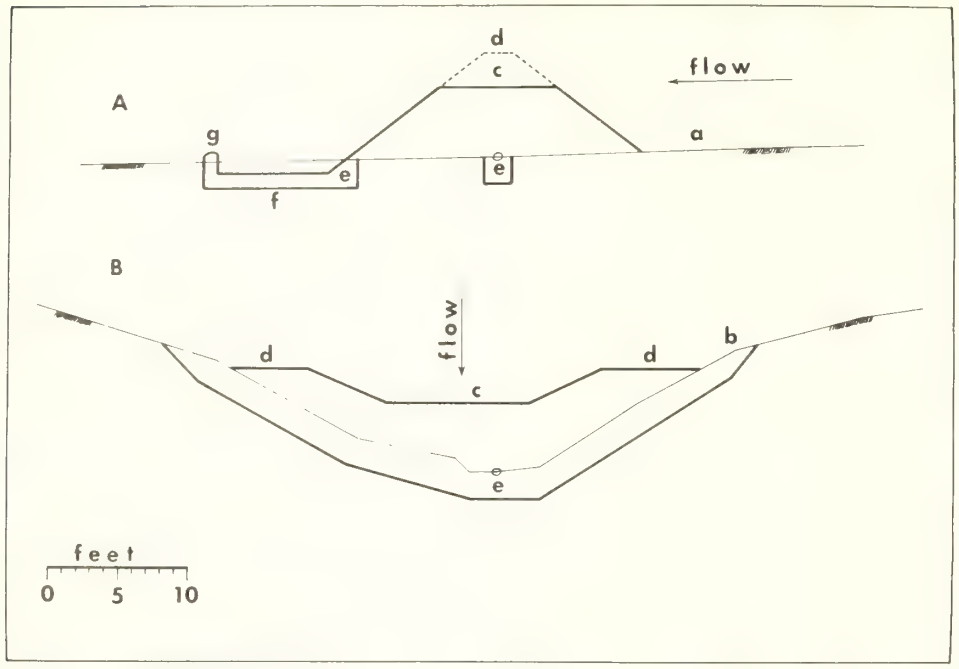
A check dam that is either too small or too large to achieve its objective results in a waste of funds. In a strict sense, knowledge basic to the proper design of check dams is not yet adequate to assure that they are neither over nor under designed with respect to intrinsic stability or gully control. It is apparent, however, that available knowledge can be effectively applied only when the relevant features of a prospective dam site have been fully evaluated. Careful surveys of sites are therefore prerequisite to dam design.

The gullies of the study area were surveyed with tape, survey rod, Abney hand level, and staff compass. During the survey, reference points were established alongside the gullies by use of transit and engineer's level to facilitate future resurveys. Channel gradients and alinements, bottom and upper widths, and depths of gullies were determined and drawings made of the longitudinal profiles, cross sections, and plan views. A radial-line plotter applied to aerial photographs facilitated computations of areas.

Nine gullies were randomly selected for the installation of the structures. Gully geometry and length varied greatly. Thus, the width ranged from 5 to 50 feet, the depth from 2 to 30 feet, the length from 50 to 4,400 feet, and the gradient from 3 to 18 percent.

Based on the field survey, 122 check dams and 12 head-cut controls were designed in the office. Locations of the dams were determined by the spacing requirements. Since information on gully cross sections was available only for survey stations spaced about 50 feet, it was necessary to check on the suitability of those located between the stations, and to obtain the missing survey data. The suitability of a site was evaluated by factors such as access, soil piping, or extremely wide cross section relative to neighboring locations. If a site was found unsuitable, another was chosen. In some cases, small changes in location of a dam to take advantage of a rock outcrop or a narrow channel section resulted in substantial cost savings. The spacing between the dams was checked and if the requirements were exceeded, additional dams were designed.

Figure 4a.--Construction plans for a loose-rock check dam.
A. Section of the dam parallel to the centerline of the gully.
B. Section of the dam at the cross section of the gully.



a = original gully bottom
b = original gully cross section
c = spillway
d = crest of freeboard
e = excavation for key
f = excavation for apron
g = end sill

It was desired to have equal numbers of different types of check dams. Yet, no type was assigned where it would fail.

During the field season following the period of design work, a contractor installed the structures according to the plans and under direct supervision. Motorized equipment was employed to the fullest extent possible. The rock to be used in the dams was quarried on the study area; all other construction materials were purchased on the open market.

Types of Rock Check Dams Applied

Loose-Rock Check Dams

The design of loose-rock check dams is illustrated by the plottings of the cross section of the structure and of the elevation parallel to the center line of the gully (fig. 4a). These drawings were used for the calculation of volumes of excavation and of rocks required in the construction, and later served in the field as construction plans.

Loose-rock check dams consist of rock only (fig. 4b). Since this type of structure is not reinforced, the angle of rest of the rock should determine the slopes of the dam sides. This angle depends on the type of rock, the weight, size, and shape of the individual rocks, and the size distribution among all rocks. If the dam sides are constructed at an angle steeper than that of rest, the structure will be unstable and may lose its shape during the first heavy runoff. For the design of check dams, the following rule of thumb can be used: the angle of rest for angular rock corresponds to a slope ratio of 1.25 to 1.00; for round rock, 1.50 to 1.00.

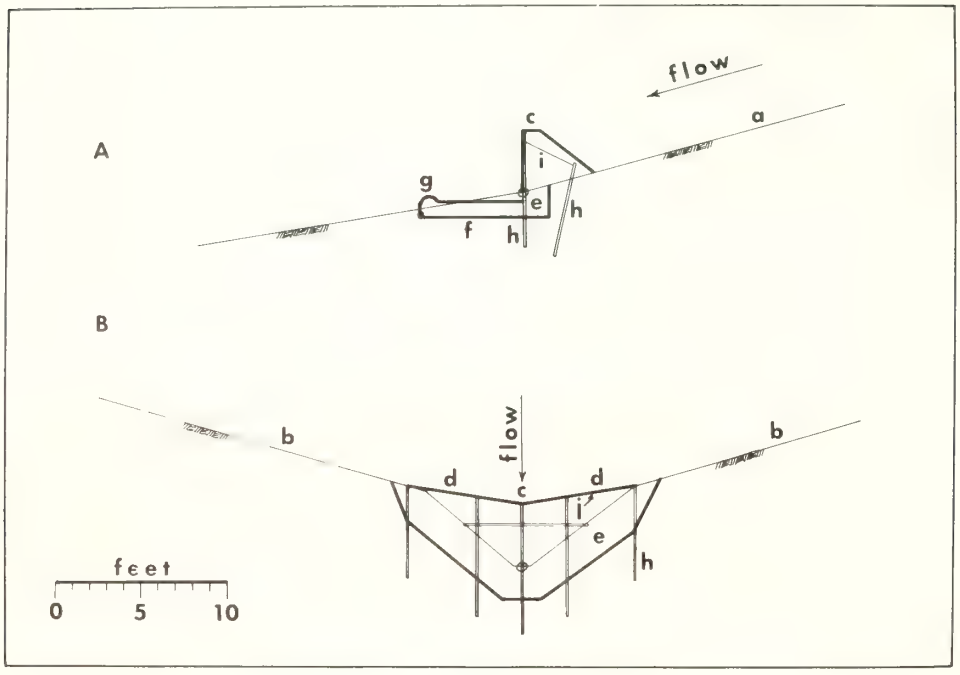
Wire-Bound Rock Check Dams

A wire-bound check dam is identical in shape to that of a loose-rock dam. It differs from the latter in that the loose rock is enclosed in wire mesh (fig. 5). The objective of the mesh is to reinforce the structure. The tension in the mesh stresses the rock and thus causes tighter anchorage of the individual

Figure 4.--Upstream view of a loose rock check dam during first runoff from spring snowmelt after construction. Heavy bouldery material scattered in this gully was collected and used together with quarry rock in the structure. The effective height of the dam is about 4 feet. Approximately 15 c.f.s. of water and sediment are discharging over the spillway.

Figure 5.--This wire-bound check dam was built from selected river rock because of temporary difficulties at the rock quarry. Some sediment collected on the apron (lower left) during the first flow from spring melt after construction. The peak flow of the snowmelt waters reached a depth of 0.75 foot in this gully, where the bottom was about 2.5 feet wide. Only a small amount of water overtopped the spillway. Most of the flow percolated through the dam. Effective dam height is 4.7 feet.

Figure 6a.--The construction plans for the single-fence rock check dam shown in figure 5b.
A. Section of the dam parallel to the centerline of the gully.
B. Section of the dam at the cross section of the gully.



a = original gully bottom
b = original gully cross section
c = spillway
d = crest of freeboard
e = excavation for key
f = excavation for apron
g = end sill
h = steel fencepost
i = guys
j = re-bar, 0.5 inch in diameter

pieces. The flexibility within the wire mesh is sufficient to permit adjustments in the structural shape, if the dam sides are not initially sloped to the angle of rest. Therefore, the same rock design criteria are required for a wire-bound dam as for a loose-rock structure.

The wire mesh should: (1) be resistant to corrosion, (2) be of sufficient strength to withstand the pressure exerted by flow and rocks, and (3) have openings not larger than the average rock size in the dam.

Single-Fence Check Dams

Single-fence rock check dams (fig. 6) differ greatly in shape and requirements of construction materials from the loose-rock and wire-bound dams. These structures consist of a wire-mesh fence, fastened to steel posts and strung at right angles across the gully, and a loose-rock fill, piled from upstream against the fence. The rock fill can be constructed at an angle steeper than that of rest because of two reasons:

1. The impact of future flows will have a tendency to push the individual rock into the fill and against the dam.
2. Expected sediment deposits will add stability to the fill and will eventually cover it.

In the design of this type of check dam, emphasis should be placed on the specifications for the wire mesh, and the setting, spacing, and securing of the steel posts. The wire mesh specifications will be the same as those for the wire-bound dams.

The steel posts should be sufficiently strong to resist the pressure of the rock fill and the flows. They must be driven into the gully bottom and side slopes to a depth that insures their stability in saturated soil. If it is impractical to drive posts to sufficient depths, the stability of the posts should be enhanced by guys. These guys should be anchored to other posts that will be covered and thus held in place by the rock fill.

In general, the fenceposts of the study dams were spaced no more than 4 feet to prevent

Figure 6b.--The crest of the spillway of this single-fence rock check dam is 3.7 feet above the original gully bottom. The rod, 5.5 feet long, was set below the dam on the apron. A backhoe placed the rock into this structure. Note the gully side-slope protection below the dam.

excessive pouching of the wire mesh. Where a maximum spacing of 5 feet was applied, the fence was reinforced by a steel post fastened horizontally between the vertical posts. Excessive pouching of the wire mesh reduces the structural height and impairs the stability of the dam.

Double-Fence Rock Check Dam

The main features of double-fence rock check dams are two wire-mesh fences, strung across the channel 2 feet apart (fig. 7). The space between the fences is filled with loose rock. Design specifications for the wire mesh and the steel posts are the same as for single-fence structures. To counteract the pressure exerted by the rock fill against both fences, guys connect opposite fenceposts.

Loose Rock Controls for Gully Head Cuts

The control of head cuts to stop headward extension of gullies is an important feature in gully treatment. Figure 8a depicts a section of the control work, plotted parallel to the center line of the gully. As in loose-rock check dams, the quality, size, shape, and size distribution of the rock are of special importance to the success of the structure, and therefore require prime consideration in the design. To make the placement of the rock against the wall of the head cut possible, this wall must be sloped back.

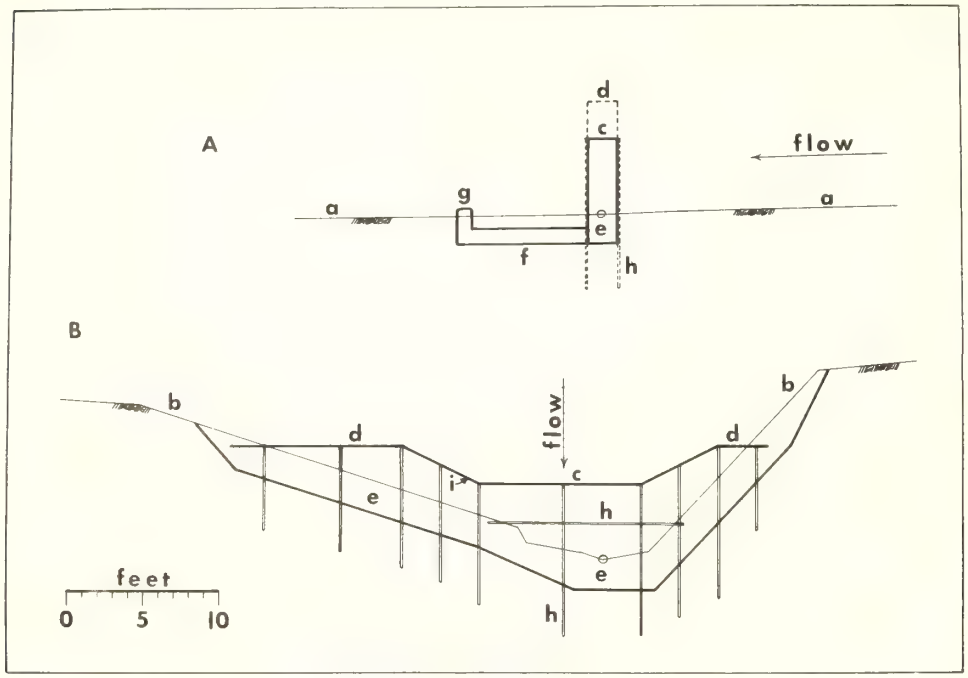
If the toe of the rock fill should give way to the forces of the expected flow, the fill would be lost. Therefore, the stabilization of this toe received emphasis in the design. A loose-rock dam was designed to act as an energy dissipator for the chuting flows and as a catch for sediment (fig. 8b). It was expected that the sediment depositions would further stabilize the toe of the rock fill by encouraging vegetation during periods without channel flows.

General Design Criteria

Rock

The quality, size, and size distribution of the rock used in construction of a check dam exert great influence on the success and life-span of the structure. It is obvious that rock that disintegrates rapidly when exposed to water and atmosphere will lead to a short structural life. Further, if only small rocks are used in a dam, they may be moved by the impact of the first large water flow, and the dam quickly destroyed. In contrast, a check dam constructed of large rocks that leave large voids in a structure will offer resistance to the flow, but may create water jets through

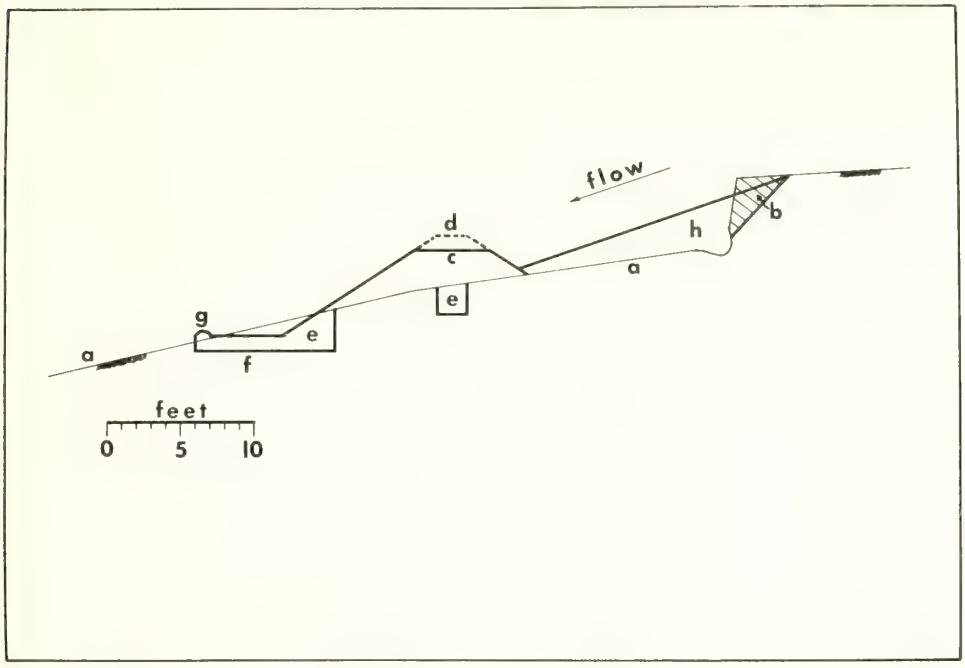
Figure 7a.--The construction plans for the double-fence rock check dam shown in figure 6b.
A. Section of the dam parallel to the centerline of the gully.
B. Section of the dam at the cross section of the gully.



a = original gully bottom
b = original gully cross section
c = spillway
d = crest of freeboard
e = excavation for key
f = excavation for apron
g = end sill
h = steel fencepost
i = re-bar, 0.5 inch in diameter

Figure 7b.--Looking upstream at a double-fence rock check dam with an effective height of 5.5 feet. Water is still standing on the apron. A small flow developed from a light storm 1 day before this photo was taken. Dam construction was finished only 1 day before the storm.

Figure 8a.--The construction plan of the gully head-cut control with a loose-rock check dam as shown in figure 7b. The section of the structures is illustrated parallel to the centerline of the gully.



a = original gully bottom
b = excavated area of head-cut wall
c = spillway
d = crest of freeboard
e = excavation for key
f = excavation for apron
g = end sill
h = rock fill

Figure 8b.--Looking upstream on a loose-rock check dam installed at the toe of a rock fill of a former gully head cut in July 1961. The rod on the apron of the check dam is 5.5 feet long. The depth of the former head cut was 5.8 feet. The photo, taken on September 2, 1964, indicates the stabilization of channel and head cut. This gully experienced several spring melt flow seasons and some small flows from summer storms. Little sediment was deposited above the dam.

the voids (fig. 9). These jets can be highly destructive if directed toward openings in the bank protection work or other unprotected parts of the channel. Large voids in check dams also prevent the accumulation of sediment above the structures (fig. 10). In general, this accumulation is desirable because it increases the stability of structures and enhances stabilization of the gully.

Large voids will be avoided if the rock is well graded. Well-graded rock will permit some flow through the structure, which will release part of the hydrostatic pressure against the dam. The majority of the rock should be large enough to resist the flow (fig. 11).

The designs were based on quarry rock, consisting of medium to hard sandstone, with diameters ranging from 0.3 to 1.0 foot. Where only loose rock was to be used in the dams, the design permitted the use of bouldery material with a diameter as large as 3 feet. The boulders occurred as a natural scattering around and within the gullied area.

Figure 10.--Downstream view. This double-fence rock check dam had accumulated sediment 1.5 feet deep during the peak flow of the spring melt season, but the almost clear recession flows carried most of the deposits through the dam. Insufficient grading of the rock had resulted in too many large rocks and great pores in the structure. A remnant of the former deposits is visible on the right side of the gully bottom.

Figure 9.--When subjected to its first heavy flows during the period of spring snowmelt, a rock check dam releases some of the hydrostatic pressure of the water through the pores of the structure.

Figure 11.--Downstream view of a successful double-fence rock check dam at the end of the spring melt following construction. The structure accumulated sediment to a depth of 1.5 feet. The last recession flow of the season is running over the deposits and through the dam. The pipes on the gully bottom and the side slope are crest gages.

Spacing

The location of a check dam will be determined primarily from the required spacing of the structures. Requirements for spacing depend on the gradients of the sediment deposits expected to accumulate above the dams, the effective heights of the dams, the available funds, and the objective of the gully treatment. If, for instance, the objective is to achieve the greatest possible deposition of sediment, widely spaced, high dams would be constructed. On the other hand, if the objective is mainly to stabilize the gully gradient, the spacing would be relatively close and the dams low.

In general, the most efficient and most economical spacing is obtained if a check dam is placed at the upstream toe of the final sediment deposits of the next dam downstream. This ideal spacing can only be estimated, of course, to obtain guidelines for construction plans.

The long-range objectives of the study reported here require spacings of check dams great enough to allow the full utilization of the sediment-holding capacity of the structures (fig. 12). To determine this spacing requires definite knowledge of the relationship between the original gradient of gully channels and that of sediment deposits above check dams placed in these gullies. This relationship has been hypothesized by several authors (Ferrel 1959, Heede 1960).[5] Woolhiser and Lenz (1965) demonstrated that not only the original channel gradient influences the deposition slope, but also the width of the channel at the structure and the height of crest of spillway above the

Figure 12.--These dams were built from loose rock only, and were spaced to allow full utilization of the catchment capacity of structures. At each check dam, the turbulent flow is transformed into more tranquil flows. Thus, if several dams are spaced in a gully, the regimen of the flows will be changed to benefit stabilization processes.

[5] *Kaetz, A. George, and Rich, Lowell R. Report of surveys made to determine grade of deposition above silt and gravel barriers. (Unpublished office report of U. S. Soil Conserv. Serv., Albuquerque, N. Mex., Dec. 5, 1939. Abstracted in bibliography of unpublished sedimentation data and annotated bibliography of upstream effects of dam construction on stream regimen, Sedimentation Subcommittee of Pacific Southwest Interagency Committee, p. 8, March 1961.)*

original channel bottom. Because relationships developed so far have been entirely empirical, further research is necessary to establish the theoretical basis.

Deposits above earth check dams existing on the study area were examined for guidance in the spacing of dams constructed under this study. Based on data so obtained, it was assumed that, in gullies of less than 20 percent gradient, the dams would not interfere with sediment catch if their spacing was predicted on the slope of the expected deposits being 0.7 of the original gully gradient. Thus, for a gully gradient of 15 percent, the gradient of the expected deposits was assumed to be 0.7 x 15, or 10.5 percent. Then for 6-foot-high dams, the spacing between dams would be 6/0.105 or approximately 57 feet.

For gully gradients exceeding 20 percent, it was assumed that expected deposits of sediment would have a gradient of 0.5 that of the gully. Thus, for a gully gradient of 24 percent, the sediment gradient would have a slope of 12 percent and the spacing between 6-foot-high dams would be 6/0.12 or 50 feet.

Keys

The keying of a check dam into the side slopes and the bottom of the gully greatly enhances the stability of the structure. Such keying is important in gullies where expected peak flow is large, and where highly erosive soils such as soils with high sand content exist. Successful loose rock check dams without keys were installed in soils derived from Pikes Peak granite and did not experience an estimated peak larger than 8 c.f.s. (Heede 1960).

The objective of the key located in the gully side slopes is to prevent destructive flows of water around the dam and consequent scouring of the banks. Scouring could lead to gaps between dam and bank that would render the structure ineffective.

The keys minimize the danger of scouring and tunneling around check dams because the route of seepage is considerably lengthened. As voids in the key become plugged, the length of the seepage route increases. This increase causes a decrease in the flow velocity of the seepage water and, in turn, a decrease of the erosion energy.

The part of the key placed into the gully bottom is designed to safeguard the check dam against undercutting at the downstream side. Therefore, the base of the key, which constitutes the footing of the dam, must be designed to be below the surface of the apron. This is of particular importance for fence-type structures because of the greater danger of scouring at the foot of these dams. The water flowing over the spillway forms a chute that creates a main critical area of impact where the hydraulic jump strikes the gully bottom. This location is away from the structure. The sides of loose-rock and wire-bound check dams slope onto the apron, on the other hand, and no freefall of water occurs.

The design of the keys called for a trench, usually 2 feet deep and wide, dug across the channel at the construction site (fig. 13). Where excessive instability was demonstrated by large amounts of loose materials on the lower part of the channel side slopes or by large cracks and fissures in the bank walls, the depth of the trench was increased to 3 or 4 feet.

Dam construction started with the filling of the key with loose rock. Then the dam was erected on the rock fill. It became apparent after the first channel flows following construction that rock size distribution in the keys should be watched carefully. In some keys, smaller rock sizes were missing, voids in the keys were large, and velocities of flow within the key led to washouts of the bank materials. Since the rock of the keys is embedded in the trench and therefore cannot be easily moved, it is advantageous to use smaller materials, such as a mixture with 80 percent smaller than 3 inches. This mixture seems to be adequate for the stability of the keys by present knowledge.

Height

The effective height of a check dam is the elevation of the crest of the spillway above the original gully bottom (fig. 14). The height not

Figure 13.--
This backhoe excavated the keys for check dams where gully cross sections were small and the construction sites easily accessible.

Figure 14.--
The effective height of check dams influences not only the volume of future depositions, but also the spacing of structures. These double-fence rock check dams were installed on a gradient of 12.5 percent.

only influences structural spacing but also volume of sediment deposits. If the objective of gully control is to deposit large volumes of sediment, higher dams are superior to lower ones. Since the volume of sediment deposited varies approximately as the square of the effective height of the dam, a 6-foot structure accumulates about 9 times as much sediment as a 2-foot dam.

The rule of thumb for spacing dams, previously given and illustrated, may be used to determine, for a given gully gradient, the ratio of low dams to high dams required for efficient gully control. In a gully of 5 percent gradient, for instance, the ratio of 2-foot to 6-foot dams is 2; in a gully of 15 percent gradient, the ratio increases to 2.5. Yet in the first instance the 6-foot dams will cause the deposition of 4.5 times the sediment stored by twice as many lower dams; with a 15 percent gradient, the higher dams will accumulate 3.6 times more sediment.

In most cases, however, dam height will be restricted by one or all of the following criteria: (1) costs, (2) stability, and (3) channel geometry in relation to spillway requirements.

Cost criteria are discussed later. Stability of rock check dams cannot be calculated without detailed experiments in field and laboratory because of unknowns such as the porosity of a structure.

A maximum height of 7 feet was set for loose-rock and wire-bound dams, and 6 feet for single- and double-fence dams. All structures were severely tested during the first snowmelt season following construction, but none was destroyed.

In gullies with small widths and depths but large magnitudes of flow, the effective height of dams may be greatly restricted by the spillway requirements. This restriction may result from the spillway depth necessary to accommodate expected debris-laden flows.

Spillway

Since spillways of rock check dams may be considered broad-crested weirs, the discharge formula for that type of weir is applicable:

$$Q = CLH^{3/2}$$

where
Q = discharge in c.f.s.,
C = coefficient of the weir,
L = effective length of the weir, and
H = head of flow above the weir crest.

The value of C varies between 2.6 and 3.6 over ranges of weir breadths from 0.5 to 15 feet and flow depths from 0.2 to 5.5 feet (King 1954). Because the exact value of C depends on the roughness as well as the breadth and shape of the weir and the depth of flow, it cannot be readily determined for the spillway of a rock check dam. Therefore, land managers conventionally apply a mean value of 3. This value appears reasonable in the light of other inaccuracies that are introduced in calculating the design storm and its expected peak flow. For this reason also, the discharge calculations would not be significantly improved if they were corrected for the velocity of approach existing above a dam. Such a correction would amount to an increase of 5 percent of the calculated discharge at a head of flow of 2 feet over a dam 2.5 feet high, or 8 percent if the flow had a 3-foot head.

For structural gully control, design storms should be of 25 years' magnitude, and, as a minimum, spillways should accommodate the expected peak flow from such a storm. In mountainous watersheds, however, where forests and brushlands often contribute large amounts of debris to the flow, the size and the shape of spillways should be determined by this expected organic material. As a result, required spillway sizes will be much larger than if the flow could be considered alone. Spillways designed with great lengths relative to their depths are very important here. Yet, spillway length can be extended only within limits because a sufficient contraction of the flow over the spillway is needed to form larger depths of flows to float larger loads over the crest. The obstruction of a spillway by debris is undesirable since it may cause the flow to overtop the freeboard of the check dam and lead to its destruction.

The characteristics of the sides of a spillway are also important for the release of debris over the structure. Spillways with perpendicular sides will retain debris much

easier than those with sloping sides; in other words trapezoidal cross sections are preferable to rectangular ones. A trapezoidal shape introduces another benefit by increasing the effective length of the spillway with increasing magnitudes of flow.

The length of the spillway relative to the width of the gully bottom is important for the protection of the channel and the structure. Normally, it is desirable to design spillways with a length not greater than the available gully bottom width so that the waterfall from the dam will strike the gully bottom. There, due to the stilling-basin effects of the dam apron, the turbulence of the flow is better controlled than if the water first strikes against the banks. Splashing of water against the channel side slopes should be kept at minimum to prevent new erosion. Spillway length may have to exceed gully-bottom width in gullies with V-shaped cross sections, or where large flows of water and debris are expected relative to the available bottom width. In such cases intensive protection of the gully side slopes below the structures is required.

Apron

Stability aspects require the installation of aprons on the gully bottom and protective works on the gully side slopes below the check dams. Without protection, flows may easily undercut the structures from downstream and destroy them.

Aprons and bank protection works were built mainly from loose rock. To simplify the design procedures, a rule of thumb was adopted: the length of the apron should be 1.5 times the height of the structure in channels where the gradient does not exceed 15 percent, and 1.75 times where the gradient is steeper than 15 percent. The resulting apron lengths included a sufficient margin of safety to prevent the waterfall from hitting the unprotected gully bottom. The design provided for embedding the apron into the channel floor so that its surface would be roughly level and about 0.5 foot below the original bottom elevation.

At the downstream end of the apron, a loose rock sill was designed 0.5 foot high, measured from channel bottom elevation to the crest of the sill. This end sill creates a pool in which the water will cushion the impact of the waterfall.

The installation of an end sill provides another benefit for the structure. Generally, aprons are endangered by the so-called ground roller that develops where the hydraulic jump of the water hits the gully bottom. These vertical ground rollers of the flow rotate upstream, and where they strike the gully floor, scouring takes place. Thus, if the hydraulic jump is close to the apron, the ground roller may undermine the apron and destroy it. The end sill will shift the hydraulic jump farther downstream, and with it the dangerous ground roller. The higher the end sill, the farther downstream the jump will occur. Since data on sediment and flow were not available, a uniform height of sill was used for all structures.

Gullies with ephemeral water carry frequent flows of small magnitudes. Therefore, it is advisable not to raise the crest of the end sills more than 0.5 to 0.75 foot above the gully bottom. End sills, if not submerged by the water, are dams and create waterfalls that may scour the ground below the sill. Usually, at higher flows some tailwater exists below a sill and cushions to some extent the impact from the waterfall over the sill.

Where the downstream nature of the gully is such that appreciable depth of tailwater is expected, the installation of end sills is not critically important. The hydraulic jump will strike the water surface and ground rollers will be weak.

Side-Slope Protection

Investigations have shown (Heede 1960) that check dams may be destroyed if flows scour the gully side slopes below the structures and produce a gap between the dam and the bank. Since intensive turbulence exists in the water below a check dam, eddies develop that flow upstream along each gully side slope. These eddies are the cutting forces. If it were practical, these currents could be prevented by the installation of long sills on the apron (Morris and Johnson 1943, U. S. Bureau of Reclamation

1960). These sills would separate the areas of fast flow from those of low velocities at each side of the stream. Gully channels are usually too narrow for the construction of long sills, however, and it is easier to install protective works directly on the channel side slopes.

Loose rock was applied directly for bank protection. In all cases, the design provided for excavation of the side slopes to a depth of about 1 foot. The objective of this excavation was to permit placement of the rock flush with the surrounding side slope surface to increase stability of the protection (fig. 15). Excavation of surface materials also assured that the rock would not be set on vegetation that could weaken the bank protection.

Where the gully side slopes were steeper than 1.25 to 1.00, a wire mesh fence, secured to steel posts, was designed approximately flush with the original slope surface, and the space behind the fence filled with loose rock (fig. 16). The fence added strength to the protective works and prevented displacement of the rock.

Figure 15.--The rod, 5.5 feet long, is placed on apron of this double-fence rock check dam. Note the rock for gully side-slope protection is embedded in the soil without reinforcement by a fence.

The height of the bank protection depends on the characteristics of channel, flow, and structure. Where gullies have wide bottoms, and spillways are designed to shed the water only on the channel floor, the required height will depend on the depth of the tailwater expected on the apron. But where the waterfall from a check dam will strike against the gully banks, bank protection must be of sufficient height to prevent the water from splashing against unprotected bank areas. Otherwise, new erosion may be initiated.

In gullies with V-shaped cross sections, the height of the bank protection was made equal to the elevation of the upper edges of the freeboards of the structures. In general, with increasing distance from the dam, the height of the bank protection decreased.

Construction

Motorized equipment was utilized to the fullest extent possible in the construction of the check dams. Hand labor was used only for work that could not be satisfactorily performed by machinery. In general, besides the equipment and its operators, not more than two laborers were employed in the construction. For most operations, conventional types of

Figure 16.--
At this double-fence rock check dam, steepness of the side slopes required that the rock side-slope protection be stabilized with a fence.

equipment were used: backhoe, clam shell, crawler-type tractor with blade, air compressor, dump truck, and bucket loader. Since conventional post-driving equipment, such as a pile driver, is not suitable for the construction of check dams, an attachment to a pavement breaker was designed (Heede 1964). This breaker, driven by an air compressor, was easy to handle in the gullies and drove steel posts efficiently into the dense, cohesive soils.

Before construction started, the following design features were staked and flagged conspicuously:

1. The centerline of the dam or the key trenches, respectively, was marked on each bank. The stakes were set away from the gully edge to protect them during construction.
2. The crest of the spillway was designated by a temporary bench mark in the gully side slope sufficiently close to be of value for the installation of the dam.
3. The downstream end of the apron was marked.
4. For loose-rock and wire-bound dams, the upstream and downstream toes of the dam proper were flagged.

This amount of staking greatly facilitated dam construction. Caution was required during excavation, however, to avoid destroying the stakes before the main work of installation began.

The construction of all dams started with the excavation for the structural key, the apron, and the bank protection. This very important work was performed by a backhoe, which also cleaned vegetation and loose material from the site.

Since all trenches were designed to have a width of 2 feet, a 1.5-foot-wide bucket was used on the backhoe. Two types of backhoes were used. One was mounted on a rubber-wheeled vehicle and operated from a turntable, which permitted the backhoe to rotate 360 degrees. This machine traveled rapidly between locations where the ground surfaces were not rough, and worked very efficiently in gullies whose side slopes and bottoms could be excavated from one or both channel banks. The other type of backhoe was attached to a crawler tractor. This type proved to be advantageous at gullies that were difficult to reach, and with widths and depths so large that the backhoe had to descend into the channel to excavate. In deep gullies with V-shaped cross sections, temporary benches on the side slopes were necessary. Often, the bench was constructed by the tractor with blade before the backhoe arrived.

After the excavation was finished, trench and apron were filled by dumping rock from dump trucks. Where gully cross sections were so large that dumping did not completely fill them, the backhoe was used to finish the job.

The dump trucks were loaded by a bucket loader at the stockpile on the watershed. The bucket scooped up a certain amount of soil along with the rock, which later was dumped with the rock into the structures. Since soil is undesirable in a rock check dam because of the danger of washouts by future flows, a bucket with a grilled bottom would have been more suited. Most of the soil could have been removed from such a bucket by shaking it before the trucks were loaded. Other devices such as a grilled loading chute would also have been applicable.

If loose-rock check dams were to be constructed, the dumping operations continued after any large openings in the trench or apron had been filled with rock. For structural stability, as much volume of rock was piled up by dumping as possible. This assured a greater density in the structures, and dam sites were closer to the angle of rest of the rock than if the rock were piled by hand. Gully geometry sometimes restricted the dumping of rock, such as at deep channels where the direction of rock fall could not be controlled, or at wide channel sections where the dumped material would not reach the center of the gully. In these cases, the rock was dumped on the gully bank and the backhoe placed the rock in the structure. In gully reaches more than 20 feet deep, the backhoe was not practical and a clam shell was used (fig. 17) on a 42-foot boom attached to a turntable. The machine also placed the rock for the bank protection. Hand labor was required only for the last finish work on the structures.

Special attention was needed at the spillway and freeboard. In loose-rock and wire-bound structures, where the shape of the dams is not outlined by a fence as in the other types, experience showed there is a tendency to construct the spillways smaller than designed.

A commercial, galvanized stock fence, 4 feet wide was used in the construction of dams that required the use of wire mesh. The stay and line wires were of 12-1/2-gage low-carbon steel, the top and bottom wires of 10-gage low-carbon steel, and the openings in the mesh were 6 inches. To connect ends of the fence or to attach the fence to steel posts, a galvanized 12-1/2 gage coil wire was used.

For wire-bound dams, the wire mesh of required length and width was placed on the gully bottom and side slopes after the trench and apron had been filled with rock (fig. 18). The required dimensions of the wire mesh were taken from the construction plans. Generally, several widths of mesh were needed to cover a structure from bank to bank. If several sheets of the fence material were required, the sheets were wired together with coil wire where they would be covered with rocks. The parts to be unburied were left unattached to facilitate the fence-stringing operations around the structure.

Figure 17.--A clam shell empties rock into a double-fence structure. Note the reinforcing fence for the gully side-slope protection.

Figure 18.--
The trench across the gully, representing the key of the planned wire-bound check dam, and the apron are filled with rock. The wire-mesh mat is placed on the fills. After this mat has been temporarily fastened to the gully side slopes, the construction of the dam proper can start.

Before the rock could be placed on the wire mesh for the installation of the dam proper, the mesh had to be temporarily attached to the gully banks. Otherwise, the wire mesh, lying on the gully side slopes, would be pushed into the gully bottom by the falling rock and buried. Usually, stakes were used to hold the wire mesh on the banks.

After the dam proper had been placed and its final shape attained, the fence was bound around the structure. Fence stretchers were applied to pull the upstream ends of the fence material down tightly over the downstream ends, where they were fastened together with coil wire. Then the bank protection below the dam was installed.

The installation of single- and double-fence dams began with the construction of the fences after excavation was completed (fig. 19). Construction drawings had to be followed closely here because the final shapes of the dams were determined by the fences. Conventional steel fenceposts from 5.5 to 10 feet long were used. In some locations, the great height of posts offered difficulties for the operator of the driving equipment. Where gully bottoms were wide and accessible, the powerwagon that carried the air compressor, air hoses, pavement breaker, and fence materials was driven to the construction site and served as scaffold for the operator. When the gully was inaccessible, scaffolds were improvised.

At single-fence dams, dumping of rock was practical if the gully was not excessively deep or wide. At double-fence structures, a backhoe or clam shell was always required. The rock was placed in layers, and each layer was inspected for large voids by a man on the ground. The large voids were closed manually by rearranging rocks.

Much time and effort can be saved during construction if a realistic equipment plan is established beforehand. Such a plan requires an intimate knowledge of the cross-sectional dimensions of the gullies and their accessibility to motorized equipment. The amount of pioneer roads that will be needed because of lack of access is not only important for equipment considerations, but will also enter into the cost of the construction.

As a general rule, it appeared to be advantageous to use heavier and larger sized equipment if its mobility was adequate. Although hourly costs for heavier machines are usually greater, the total costs for a job are reduced if larger operations are involved.

With a few exceptions, conventional construction equipment is not sufficiently mobile to operate in rough topography without pioneer roads. In watershed rehabilitation projects such as gully control, roads are undesirable because any road construction disturbs the ground surface and may lead to new erosion.

Limited mobility of the machinery originated from one or all of the following factors: (1) insufficiently powered engines, (2) large total weight of the machinery, and (3) mounting of the equipment on rubber wheels. A good example was the backhoe. If a crawler-type backhoe with a powerful engine was used, the total weight of the equipment was so large that it could not climb slopes steeper than 20 percent. If a crawler-type backhoe with lesser weight was used, the engine lacked the power for unlimited operations in rough topography, and pioneer roads were needed.

Costs

During construction, detailed records were kept on time and materials expended for each work phase and structure. The absolute values of our costs, based on these records, may be unrealistic for conditions different from those of our watershed. But the indices of these values give an insight into the intricate relationships between costs of different types of check dams and between costs of dams and channel characteristics. These indices will hold true also for other watersheds.

Table 1 shows the expenditures of materials, work time, and funds required for the placement of 1 cubic yard of structure. These data should be regarded as approximations for the following reasons:

1. Sizes of samples varied greatly between the types because changes in the original design were required during construction.
2. The data for all dams within one type were averaged, regardless of height of dam, gradient, or width of gullies.
3. Dam heights ranged from 1.5 to 7 feet, but were not evenly distributed within or between the types. Most of the dams had an effective height from 2 to 5 feet.

Therefore, in evaluating the cost per cubic yard of structure, emphasis should be placed on the cost relations between the different types of dams. The cost per cubic yard is smallest for check dams built from loose rock, and greatest for a double-fence structure. The reason for this relationship is that all dams with the exception of the loose-rock

Figure 15.--Installing fences for a double-fence rock check dam.

type require additional materials such as wire mesh and steel posts. The relations are expressed as cost indices in the table. For example, on the average, 1 cubic yard of a loose-rock structure costs 32 percent less than 1 cubic yard of double-fence type.

In accordance with general experience in economics, our data demonstrate that the cost of 1 cubic yard of structure decreases with increased effective height:

	Effective height of dam	
	(2 feet)	(6 feet)
Type of check dam:		
Loose rock	$12.81	$11.18
Single fence	17.59	14.99
Double fence	17.59	15.65

Check dams were grouped by effective height in table 2. For each group, five gully sites were randomly selected and three different types of dams were designed for each

Table 1.--Expenditures for the placement of 1 cubic yard of loose-rock check dam

Type of check dam, number of dams, and cost per unit	Materials					Machine time					Hand labor	Total cost	Cost index
	Rock	Wire mesh	Coil wire	Re-bar	Steel posts	Air compressor	Backhoe	Clam shell	Loader and dump truck	D-7 tractor			
	Cu. yd.	-- Linear ft. --			Number	---------- Hours ----------							
Double-fence:													
40 dams	1	6	3	1.6	1.2	0.16	0.16	0.06	0.25	0	0.57	$16.69	1.00
Single-fence:													
12 dams	1	4	2.4	2.3	.8	.14	.12	0	.25	0	.51	14.59	.87
Wire-bound:													
7 dams	1	6.4	.6	0	0	0	.05	0	.25	0	.48	12.16	.73
Loose rock only:													
53 dams	1	0	0	0	0	0	.09	0	.25	.02	.02	11.30	.68
	---------- Dollars ----------												
Cost per unit of measure	8.03	0.083	0.004	0.07	1.00	7.00	11.00	12.00	8.00	12.00	2.17		

Table 2.--Development of rock volumes and installation costs of different types of check dams with different effective heights

Effective height of dam (Feet)	Type of dam	Relative rock volume	Cost index[1] per cubic yard	Relative cost of dam
		Percent		Percent
2	Double-fence	100	1.00	100
	Single-fence	120	.87	104
	Loose rock only	186	.68	126
3	Double-fence	100	1.00	100
	Single-fence	144	.87	125
	Loose rock only	230	.68	156
4	Double-fence	100	1.00	100
	Single-fence	150	.87	131
	Loose rock only	262	.68	178
5	Double-fence	100	1.00	100
	Single-fence	164	.87	143
	Loose rock only	273	.68	186

[1] Based on average costs shown in table 1.

site. Rock volumes for each type were compiled and, based on the volume requirements of the double-fence structure, the relative volumes of the dams were computed. When these relative figures were multiplied by the respective costs of placement, the relative costs of the dam types by effective height were obtained. The data demonstrate that double-fence dams require less rock and are thus cheaper to install than the other types. This advantage increases with increasing height of structure and cost of rock.

The above cost relationships hold true if total gully treatments by the different types of dams are compared. In table 3, rock volumes and costs required for the treatment of two gullies with gradients of 5 and 15 percent, respectively, are compiled. Loose-rock, single-fence, and double-fence structures with effective heights of 2 and 6 feet are considered. The data on the total cost of gully treatments show that, regardless of the gully gradient, treatment with double-fence dams is cheaper. It also follows that cost of gully control increases with increasing gully gradient between 5 and 15 percent.

Table 3 illustrates further that reducing the total number of check dams in a gully by increasing the effective height of the structures usually does not save installation costs.

Table 3.--Installation costs of loose-rock check dams, by gully gradients and effective structural heights

Type of check dam and gully gradient (Percent)	Effective height of dam	Total dams required	Volume of rock--		Installation cost--		Cost ratio
			in one dam	Total	for 1 cubic yard	Total	
	Feet	Number	Cubic yards				
Double-fence:							
15 percent	2	10	6.5	65.0	$17.59	$1,143.35	0.84
	6	4	15.4	61.6	15.65	964.04	
5 percent	2	2	6.4	12.8	17.59	225.15	1.07
	6	1	15.4	15.4	15.65	241.01	
Single-fence:							
15 percent	2	10	7.5	75.0	17.59	1,319.25	1.24
	6	4	27.2	108.8	14.99	1,630.91	
5 percent	2	2	8.1	16.2	17.59	284.96	1.56
	6	1	29.6	29.6	14.99	443.70	
Loose rock only:							
15 percent	2	10	12.1	121.0	12.81	1,550.00	1.61
	6	4	55.9	223.6	11.18	2,499.85	
5 percent	2	2	12.0	24.0	12.81	307.44	1.99
	6	1	54.7	54.7	11.18	611.55	

Savings can be achieved only if higher double-fence dams are installed on a gradient steeper than 5 percent.

The cost ratios show further that a treatment by 6-foot dams may cost as much as 100 percent more than by 2-foot dams. With increasing gully gradient, the cost ratios decrease.

The cost relationship between the treatments by different types of structures with different effective heights can be explained by the geometry of the dams. Gully gradient and height of structure influence this geometry, which in turn determines the volume. Thus, rock volumes in loose-rock dams increase much more with height than those of single-fence or double-fence types. Due to the structural geometry also, volumes of single-fence types of a given height decrease with increasing gully gradient, while volumes at double-fence dams do not change.

Results and Recommendations

1. A good-quality, well-graded rock should be used in rock check dams. Most of the rocks should be sufficiently large and heavy to resist the impact of the flows.
2. The rock used for filling the keys of the check dams should be smaller (80 percent smaller than 3 inches).
3. Although the general locations of check dams will be determined by spacing requirements, the final structural sites should be selected on the basis of gully characteristics that benefit construction and costs.
4. In gullies with cohesive soils, keys with depth and width of 2 feet were sufficient.
5. For adequate protection of gully bottoms and side slopes, the length of apron and side slope rock-work should be 1.5 times the dam height where the gully gradient is 3 to 15 percent, and 1.75 times dam height for steeper gully gradients.
6. Spillways of check dams, installed on forested or brushland watersheds, should be designed to accommodate not only the expected peak flow, but also the debris in the flow. In general, such a design will result in requirements for discharge capacities much larger than those derived from peak flow calculations only.
7. Cross sections of spillways should be trapezoidal. Discharge capacity increases rapidly with depth of flow over the spillway, and debris can be more easily carried through the spillway.
8. If the spillway is wider than the gully bottom, the channel side slopes below a rock check dam shall be protected to the crest of the free boards of the structures.
9. Where tail waters do not occur below a check dam, a low end sill should be installed at the apron to force the ground roller, developed by the hydraulic jump, away from the apron.
10. Types of conventional construction equipment, as often used by land managers, are

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Yield Tables for Managed Stands with Special Reference to the Black Hills

by

Clifford A. Myers

Yield tables that show, or are convertible to show, potential production in even-aged managed stands are becoming ever more necessary in the United States. Many forests are already fully managed and can benefit from refinements in operations that are guided by comparison of actual conditions with a good standard. Vast areas are being converted from virgin forests to managed stands. Yield tables that show what can be accomplished by good management practices provide goals toward which conversion can be directed. Unfortunately, useful tables are not generally available for American species and forest regions.

Normal yield tables, the type usually available, are based on a concept that is invalid in many areas. Stand densities defined as "normal" may actually represent severe overstocking. This is the case with interior ponderosa pine, where full stocking is better indicated by root closure than by space occupied by tree crowns. "Normal" stocking is so often in excess of that necessary to meet management goals that recommendations have frequently been made to accept 50 to 70 percent of yield table values as standard. Such recommendations are of limited value where "normal" stocking represents slow growth or stagnation, and thus implies abnormal relationships between tree diameter, height, and age. How is an adjustment to 50 percent of normal yield table values to be interpreted, where 50 percent of normal basal area can produce 200 percent of normal merchantable volume? Unless adjustment procedures can successfully cope with such situations, normal yield tables cannot be used to predict production in managed stands.

Empirical yield tables, based on normal yield table procedures except for the concept of normality, may not be an improvement over normal yield tables. Stand densities sampled may be far from management objectives where uncut or conservatively cut stands are numerous.

A more reasonable approach is to observe carefully thinned and measured plots for one or more cutting cycles. A limited series of plots will provide data for experience yield tables that describe response to certain management procedures. Data from a larger series that samples across the ranges of important stand variables can be analyzed by multiple regression methods and summarized in variable-density yield tables.

Yield plots tie up much of the limited supply of research time and money, and provide answers slowly. Research resources may be sufficient to cope with plot installation and measurement now for only one or two important species or types in each forest region. It is unreasonable to expect demands for information to be met in such fashion simultaneously for all forest types or species.

Yield tables for managed stands can be prepared quickly and inexpensively from data collected on temporary plots. Procedures for doing this for pure, even-aged stands are presented here as a series of steps that describe field and office operations. The method provides current answers to current demands for information. For many species, such work could be the only type of yield study possible for many years.

General Description of Method

Most forest regions contain stands that have been thinned one or more times to densities near desirable management levels. These stands provide a readily available store of growth information. They also provide a basis for good estimates of desirable stocking levels for managed stands. The method described here makes use of such stands and published and unpublished information to obtain estimates of yields in managed stands that do not yet exist.

Ten items of information are needed to prepare yield tables for even-aged managed stands. Two items are determined initially; they summarize management goals for the species and guide field sampling. The other eight items can be obtained from available information and a season's field work if such tools as volume tables and site index curves are already available.

Initial management decisions are as follows:

1. Description of young stands prior to initial thinning. This involves several management decisions, including the regeneration system used to create the young stands.
2. Estimates of stocking immediately after thinnings or other intermediate cuttings throughout a rotation. This is about equivalent to a thinning guide for well-managed stands.

The eight working tools to be developed from field data and available information are as follows:

1. Largest diameters in unthinned young stands in relation to average stand diameter.
2. Stand tables for unthinned young stands of known average stand diameter.
3. Equation for estimating the periodic increase in stand diameter for various combinations of stand density and site quality.
4. Increase in stand diameter solely as a result of thinning.
5. Equation for estimating the periodic increase in basal area for various combinations of stand density and site quality.
6. Average height of dominant and codominant trees in stands of various ages where height growth has not been reduced by high stand density.
7. A stand volume equation in cubic feet with independent variables available from the other listed items.
8. Factors to convert volumes per acre from cubic measure to other units.

Once the 10 items are available, yield tables are derived as a series of projections. Starting point of the projections is defined by the description of young, unthinned stands and management decisions related to them. Growth of the stands is estimated by the diameter growth equation, the height-age relationship, and the effect of thinning on average stand diameter. Reductions in stand density due to intermediate cutting are specified by the stocking standards to be followed as management goals.

Inclusion of management decisions in the procedure is unavoidable because the yield tables are for managed stands. With the methods described here, however, management decisions may be changed freely to match changes in product objectives or silvicultural goals. Most working tools that come from field data and represent the expenditure of time and money will not change. Anyone can use the working tools to prepare yield tables for managed stands that describe what will happen after application of his concept of good management.

Yield tables for managed stands of ponderosa pine (Pinus ponderosa Laws.) in the Black Hills of South Dakota and Wyoming were derived as an example of procedure. Management decisions on which the yield tables are based were determined by characteristics of Black Hills stands and probable future management goals. Foresters working in the Black Hills who do not agree with these decisions can easily substitute their own. Foresters interested in the method but not in Black Hills stands can follow the procedure, substituting decisions and data applicable to their area.

Initial Management Decisions

Two sets of decisions must be made before field work can be planned: (1) how stands are to be regenerated and the appearance of these stands early in a rotation, and (2) stocking to be maintained throughout a rotation to meet product and other objectives. Data on which to base these decisions are readily available where young even-aged stands exist, and where results of thinning studies are available or can be simulated by increment cores. Some data can be gathered on temporary plots; other data are in the literature. Because needs will vary locally, they are not discussed in the section

on field work. Decisions to be made and data needed to make them can be determined from the following sections.

Stands Prior to Thinning

Description of the early life of a stand includes:

1. Number of trees per acre at the earliest stand age to be considered in the yield tables. Regeneration system used to create the stand must be determined at this point.
2. Age when stands of this density will first need thinning.
3. Mortality in numbers of trees each 10 years, or other period, from the earliest age of interest to age at first thinning.
4. Average stand diameter at the end of each 10 years, or other period, from the earliest age of interest to age at first thinning.

Ways to obtain such descriptive material are illustrated by decisions made for ponderosa pine in the Black Hills.

1. Desirable number of trees per acre at age 10 was estimated to be about 2,000. Examination of numerous young stands of ponderosa pine in the Black Hills and in Arizona indicated that a moderate stand density will insure the formation of straight boles. High densities that lead to slow growth and stagnation (Myers 1958, Myers and Van Deusen 1960b)[2] and low densities that encourage the development of "apple trees" must be avoided.
   A stand of 2,000 seedlings per acre can be attained in the final steps of regeneration cutting by uniform shelterwood. The final cut will destroy some seedlings; undisturbed patches can be opened with brush axes or other tools that quickly lop trees not needed. Future research may reveal that desired density can be obtained by controlling the amount of shelterwood and the time it is removed. In any event, it is not necessary to save exactly 2,000 seedlings, or exactly any other number used as a guide.
2. Thinning will probably be unnecessary in stands less than 30 years old if density at age 10 is about 2,000 trees per acre. Desirable stand density (decision one, above) was determined first. Then, borings were made in dominant and codominant trees 10 to 50 years old to observe the effects of age and stand density on radial growth.
3. Examination of numerous unthinned young stands where mortality could be dated with reasonable accuracy indicated that 2,000 trees per acre would be reduced to about 1,850 after 10 years. No differences due to site quality could be found. Mortality estimates to age 30 varied with site quality, as shown in the yield tables (see tables 6-9).
4. Average stand diameter before initial thinning was determined from measurements of moderately stocked, unthinned stands 25 to 35 years old. Diameter and basal area growth equations applicable to unthinned stands were used to check the diameter-age relationships obtained (Myers and Van Deusen 1961).

Stocking After Cutting

Stocking to be left after each intermediate cutting is an important management decision because of its effect on growth and yield. Reserve density will vary with age or diameter of the stand, site quality, and the objectives of management.

One way to choose stocking levels is illustrated by decisions made for Black Hills ponderosa pine. The decisions and reasons for them were as follows:

1. Stocking would be expressed by a relationship between basal area and average stand diameter. Basal area is an easily measured variable (Grosenbaugh 1952) that is highly correlated with growth in size and volume (Myers and Van Deusen 1961).
2. Basal area left after cutting would increase with stand diameter until a specified diameter was reached. Thereafter, equal basal areas would be left after each intermediate cutting. For the Black Hills, basal area would be held constant after stand diameter reached 10 inches.

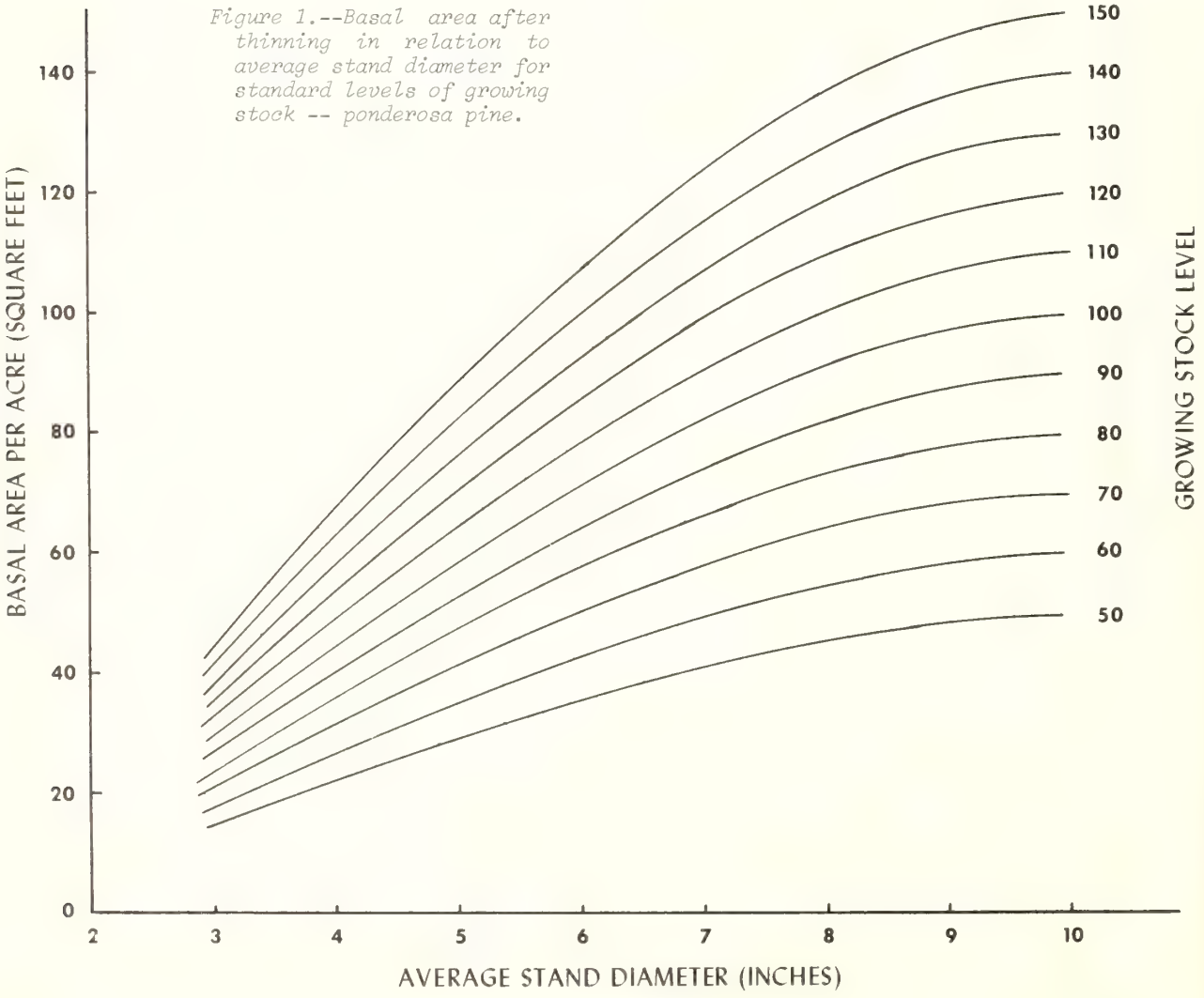
[3] *parentheses refer to*

3. Several basal area-diameter relationships would be equally acceptable as standard to provide for variation in management goals.
4. Age would not be used in the definition of stocking levels. Many stands had gone through periods of slow growth or suppression. Relationships between age and diameter or between age and merchantable volume were expected to be different under management.

Once these decisions had been made, published (Myers 1958) and unpublished results of thinning experiments dating back to 1909 were examined. For each stand diameter represented, the residual basal area tested that appeared best was determined. Major factors considered in the ratings were growth per acre in cubic volume to a 4-inch top, and probable length of saw log rotations. Site quality was ignored since most results were from areas of average site index.

Basal areas that appeared best were plotted over corresponding stand diameters, and a curve was drawn through the points. The points defined the curve so well that almost no balancing was necessary. This curve (level 80 of fig. 1) was accepted as the optimum growing stock for managed stands on areas of average site quality. Other curves were drawn at various percentages of basal area above and below the level 80 curve so that they passed through 50, 60, 70, etc. square feet at a d.b.h. of 10 inches. Form of the resultant curves of basal area on diameter (fig. 1) resembled curves of basal area on age for normal stands (Meyer 1938).

Figure 1.--Basal area after thinning in relation to average stand diameter for standard levels of growing stock -- ponderosa pine.



The curves define optimum growing stock for various management objectives, including the possibility of holding stand density above or below levels that give the best saw log and pulpwood production. Basal areas are readily converted to numbers of trees per acre (table 1) or to other guides for the conduct of actual thinning operations.

Specific stocking goals will hereafter be referred to as stocking level 80, stocking level 90, and so forth. A given level is defined by a curve of fig. 1, and is named by the basal area to which the stand is cut after diameter reaches 10 inches. A level is also described by the column of table 2 headed by the number that names the level.

Table 1.--Number of trees per acre after thinning, in relation to average stand diameter. Standard levels of growing stock for ponderosa pine in the Black Hills.

Average stand d.b.h. after thinning (Inches)	Growing stock level						
	60	70	80	90	100	110	120
	Number						
1.0	505	589	665	757	841	925	1,009
1.5	451	526	602	677	752	827	902
2.0	423	494	565	635	705	776	846
2.5	389	454	518	584	649	714	779
3.0	360	421	480	541	601	661	721
3.5	332	388	443	499	554	609	665
4.0	302	353	403	454	504	554	605
4.5	279	325	371	418	464	511	557
5.0	257	300	343	385	428	471	514
5.5	235	274	313	352	391	430	469
6.0	216	252	288	324	360	396	433
6.5	199	232	265	298	331	365	398
7.0	184	214	245	276	306	337	368
7.5	169	197	225	253	282	310	338
8.0	156	182	208	234	260	286	312
8.5	143	167	191	215	239	263	287
9.0	132	153	175	197	219	241	263
9.5	120	140	161	181	201	221	241
10.0	110	128	147	165	183	202	220
11.0	91	106	121	136	152	167	182
12.0	76	89	102	115	127	140	153
13.0	65	76	87	98	108	119	130
14.0	56	65	75	84	94	103	112
15.0	49	57	65	73	81	90	98
16.0	43	50	57	64	72	79	86
17.0	38	44	51	57	63	70	76
18.0	34	40	45	51	57	62	68
19.0	30	36	41	46	54	56	61
20.0	28	32	37	41	46	50	55

Table 2.--Growing stock levels for Black Hills ponderosa pine. Basal areas after intermediate cutting in relation to average stand diameter.

Average stand d.b.h. after cutting (Inches)	Growing stock level							
	50	60	70	80	90	100	110	120
	Square feet per acre							
2.0	7.7	9.2	10.8	12.3	13.8	15.4	16.9	18.4
2.2	9.0	10.8	12.6	14.4	16.2	18.0	19.8	21.6
2.4	10.4	12.4	14.5	16.6	18.7	20.8	22.8	24.9
2.6	11.8	14.2	16.5	18.9	21.3	23.6	26.0	28.4
2.8	13.3	16.0	18.6	21.3	24.0	26.6	29.3	32.0
3.0	14.8	17.7	20.6	23.6	26.6	29.5	32.4	35.4
3.2	16.2	19.5	22.8	26.0	29.2	32.5	35.8	39.0
3.4	17.8	21.3	24.8	28.4	32.0	35.5	39.0	42.6
3.6	19.2	23.0	26.9	30.7	34.5	38.4	42.2	46.0
3.8	20.6	24.7	28.8	32.9	37.0	41.1	45.2	49.4
4.0	22.0	26.4	30.8	35.2	39.6	44.0	48.4	52.8
4.2	23.5	28.2	32.9	37.6	42.3	47.0	51.7	56.4
4.4	24.9	29.8	34.8	39.8	44.8	49.8	54.7	59.7
4.6	29.4	31.6	36.9	42.2	47.5	52.8	58.0	63.3
4.8	27.9	33.4	39.0	44.6	50.2	55.8	61.3	66.9
5.0	29.2	35.0	40.9	46.7	52.5	58.4	64.2	70.0
5.2	30.5	36.6	42.7	48.8	54.9	61.0	67.1	73.2
5.4	31.8	38.2	44.5	50.9	57.3	63.6	70.0	76.4
5.6	33.0	39.6	46.2	52.8	59.4	66.0	72.6	79.2
5.8	34.2	41.0	47.9	54.7	61.5	68.4	75.2	82.0
6.0	35.4	42.4	49.5	56.6	63.7	70.8	77.8	84.9
6.2	36.6	43.9	51.2	58.5	65.8	73.1	80.4	87.8
6.4	37.7	45.2	52.8	60.3	67.8	75.4	82.9	90.4
6.6	38.8	46.5	54.2	62.0	69.8	77.5	85.2	93.0
6.8	39.9	47.8	55.8	63.8	71.8	79.8	87.7	95.7
7.0	40.9	49.1	57.3	65.5	73.7	81.9	90.1	98.2
7.2	41.9	50.2	58.6	67.0	75.4	83.8	92.1	100.5
7.4	42.8	51.3	59.8	68.4	77.0	85.5	94.0	102.6
7.6	43.6	52.4	61.1	69.8	78.5	87.2	96.0	104.7
7.8	44.5	53.4	62.3	71.2	80.1	89.0	97.9	106.8
8.0	45.3	54.4	63.4	72.5	81.6	90.6	99.7	108.8
8.2	46.1	55.4	64.6	73.8	83.0	92.2	101.5	110.7
8.4	46.8	56.2	65.5	74.9	84.3	93.6	103.0	112.4
8.6	47.4	56.8	66.3	75.8	85.3	94.8	104.2	113.7
8.8	47.9	57.5	67.1	76.7	86.3	95.9	105.5	115.0
9.0	48.4	58.1	67.8	77.5	87.2	96.9	106.6	116.2
9.2	48.9	58.6	68.4	78.2	88.0	97.8	107.5	117.3
9.4	49.2	59.1	69.0	78.8	88.6	98.5	108.4	118.2
9.6	49.5	59.4	69.3	79.2	89.1	99.0	108.9	118.8
9.8	49.8	59.8	69.7	79.7	89.7	99.6	109.6	119.6
10.0+	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0

Development of Working Tools

Field Work

Data needed to construct the yield tables were obtained on temporary plots placed in carefully selected even-aged stands. Two

types of plot were measured. "Unthinned plots" were placed in unthinned, sapling, and small pole stands. "Growth-prediction plots" were located in thinned stands of all ages to about 40 years beyond estimated rotation age for saw logs. For the Black Hills, 43 unthinned plots and 95 growth-prediction plots were measured.

Unthinned plots were placed in even-aged stands about 30 years old with densities similar to those expected in stands described in "Stands Prior to Thinning." Densities somewhat heavier and lighter than expected were also sampled to determine the effect of variations in initial density. The measurements made on unthinned plots were: (1) plot area (at least 0.25 acre), (2) site index, and (3) diameter of each tree to 0.1 inch. These data were used to prepare stand tables for unthinned, young stands. Unthinned plots also provided information on diameter-age relationships in young stands (item 4 of "Stands Prior to Thinning").

Most data needed to prepare the working tools were obtained from growth-prediction plots. These plots conformed to the following standards:

1. Were uniform in site quality, range of tree sizes, and stand density on and adjacent to the plot.
2. Varied in area with average stand diameter. With small trees, the plots were at least large enough to contain 150 trees. In low-density or sawtimber stands, a practical minimum area was about 0.5 acre. It was rarely possible to exceed minimum area in the Black Hills because of frequent changes in stand condition and site quality.
3. Supported even-aged, thinned stands that had not been cut or otherwise disturbed within 13 years prior to measurement. The 3 years beyond the 10-year measurement period was to allow for severe adjustments in form that would not be expected in continually managed stands of low density.
4. Did not have disease or insect damage that affected growth. It was necessary, however, to sample a few stands with small amounts of western gall rust (Cronartium harknessii Moore Ex Hark) so that a wide range of stand diameters and densities would be measured.
5. Had stand diameters reasonably close to those possible in managed stands of equal age. Some leeway was found to be allowable in this standard, but all extreme conditions were rejected.

An additional restriction was placed on the stand densities sampled: Only plots with growing stock levels within a predetermined range 10 years prior to measurement were accepted in the final sample. It was decided that levels 80 and 100 (table 2) would describe the most important alternatives of management for the Black Hills. Plots with past stocking levels of 50 to 170 were therefore selected to sample conditions of interest, provide for possible variation in management goals, and measure a range of conditions that would be subject to regression analysis.

Measurements made on each plot are indicated by entries on the sample field forms (figs. 2, 3, and 4). Only values needed to carry out necessary computations are shown. Additional information can be obtained if desired, especially if local experience indicates that additional independent variables should be tested in the regression analyses.

The plot description form (fig. 2) provided spaces for recording descriptive material and the results of computations. Alternative procedures for site index determination were allowed for. Site indexes of the Black Hills plots were determined from height and age (Hornibrook 1939) where the trees were old enough and where there was no indication of reduced height growth through suppression. Elsewhere, site index was determined from soil and topography (Myers and Van Deusen 1960a). The effects of stand density could have been accounted for by applying a correction to site indexes determined from height and age (Lynch 1958).

Field measurements of living trees were those shown in the first six columns of figure 3. Each tree was given a temporary number by stapling a numbered card to it. This permitted most efficient use of small crews. The record of figure 3 was completed one column at a time, yet all data from any one tree could still be identified as such. Diameters of all trees on each plot were measured with a diameter tape. Total heights were measured

Yield Table Study -- Plot Description and Summations

Plot No. 62 (1) Species Ponderosa pine

Date 6-20-63 By CAM CPP

Location Black Hills National Forest. SW¼ Sec 33 T4N R5E BHM. 150 yds west of road junction.

Plot area 0.454 acres. Blow-up factor 2.203

* * * * * * * * * * *

Soil depth ____ ins. Slope ____ % Slope distance ____

Aspect ____ Dom. height 85 ft. Dom. age 125 yr.

Trial site index ____ ft. Correction ____ Site index 73 ft.

Thinned Several Stocking level 10 years ago 90

STAND SUMMARY, PER ACRE

Item	Present		Past	
Number of trees (live)	70	(3)	70	(4)
Basal area, total	106.67	(5)	93.18	(6)
Average D.B.H., inches	16.7	(7)	15.6	(8)
Average height, feet	83	(9)		(10)
Main stand age, years	125	(11)	115	(12)
Total cubic feet	3891.2	(13)		(14)
Merchantable cubic feet	3733.5	(15)		(16)
Board feet, Scribner	19,232	(17)		(18)
Board feet, Int-¼"	22,249	(19)		(20)
No evidence of past suppression.				

Yield Table Study -- Description of Live Trees

Plot No. 62 Species Ponderosa pine Date 6-20-63

Sheet 1 of 2 sheets

(1) Tree No.	(2) Present D.B.H.	(3) Present Ht.	(4) Present Crown	(5) Present Age	(6) 10-yr. radial growth	(7) P.I. Diam.	(8) Past D.B.H.
1	16.6	77	C	118	.35	.8	15.8
2	21.0	86	C	119	.35	.8	20.2
3	17.8	84	D	124	.40	.9	16.9
4	16.0	74	C		.40	.9	15.1
5	15.3	79	D		.40	.9	14.4
6	18.7	84	D	115	.55	1.2	17.5
7	16.6	80	C	129	.60	1.3	15.3
8	18.2	81	D	129	.80	1.8	16.4
9	15.4	76	C		.65	1.4	14.0
10	16.5	84	D	123	.60	1.3	15.2
11	17.8	86	D		.45	1.0	16.8
12	18.8	83	D	119	.50	1.1	17.7
13	10.1	81	I		.25	.6	9.5
14	18.4	90	C		.45	1.0	17.4
15	18.1	88	D	128	.45	1.0	17.1
16	11.5	77	I		.25	.6	10.9

Yield Table Study -- Diameters of Trees Dead 0-10 Years

Plot No. 62 Species Ponderosa pine Date 6-20-63

D.B.H.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Total
0											
1											
2											
3											

NONE

with an Abney level and a measured base. A sample of heights was obtained where plots contained large numbers of small trees. The record of heights provided: (1) heights (6-8) for site index determination if soil-site index was not used, (2) heights for construction of a height-diameter curve, and (3) heights (about 20) to determine average height of dominant and codominant trees. Total ages were determined from borings of dominant and codominant trees at breast height (at least 10) and at the ground line (3 to 5). Ages were determined for intermediate and overtopped trees when needed to confirm that the stand was even-aged, but were not used in computations. Radial growth of the wood at breast height was determined for each tree by boring along the best estimate of average radius.

Evidence from increment cores of past crowding or stagnation and the stand age when crowding effects began and ended were described at the bottom of figure 2.

Diameters of trees that died during the previous 10 years were recorded as inside or outside bark measurements (fig. 4). Inside bark measurements were later converted to outside bark equivalents (Myers and Van Deusen 1958). Appearance of trees dead 0 to 10 years was determined by examination on permanent plots and in stands for which date of thinning was known.

A few additional items of information should be gathered or checked in the field. For example, the effects of initial thinning and rethinning on average stand diameter can be determined by trial marking of unthinned and growth-prediction plots, as described below.

Initial Computations

Field data described in the previous section were converted to volumes and other values for each plot and per acre. Basal area and other per-acre values, average stand diameter, and site index were then used as dependent and independent variables in the solution of prediction equations as explained in the descriptions of working tools. Most operations were performed on electronic computers; a few relationships were solved graphically to avoid assumptions as to curve form.

Field data from the growth-prediction plots were reduced to amounts per acre as follows:

1. A curve of height on diameter was prepared to supply missing values where the heights of all trees had not been measured (column 3 of fig. 3).
2. Present diameter outside bark was converted to past diameter outside bark by use of radial wood growth and equations that account for bark growth (Myers and Van Deusen 1958) (columns 2, 6, 7, 8 of fig. 3).
3. Past number of trees equaled present number of live trees (fig. 3) plus any mortality during the previous 10 years (fig. 4). Past and present numbers were raised to an acre basis by multiplying with the blowup factor (fig. 2).
4. Present basal area was computed with the diameters of column 2 of figure 3. Past basal area was obtained from the diameters of column 8 of figure 3 and entries in figure 4.
5. Average stand diameter was the diameter of the tree of average basal area. This definition of average diameter applied every place this variable was used or recorded as a result.
6. Cubic- and board-foot volumes were computed with volume equations of the form $V = a + b\ D^2 H$ (Myers 1964). They were raised to volumes per acre and recorded on figure 2.
7. Present age of the main stand was the average of the ages of dominant and codominant trees (column 5 of fig. 3). Past age equaled present age minus 10 years.
8. Average height of dominant and codominant trees was obtained from columns 3 and 4 of figure 3.
9. Site index was determined by one of the two methods decided upon initially (height and age or soil site) and recorded in figure 2.

Data from unthinned plots were summarized in a manner similar to data from growth-prediction plots. Each unthinned plot furnished the following:

1. Area and blowup factor.
2. Site index.
3. Number of trees, total and by 1-inch diameter classes. (Full-inch diameter classes were used in all computations involving

diameter classes; the 9-inch class included trees from 9.0 to 9.9.)
4. Basal area.
5. Average stand diameter.

Largest Diameter in Stand

Diameter tallies from the unthinned plots were used to estimate the largest diameter in young, unthinned, even-aged stands. Largest diameter can be plotted over average stand diameter, or the relationship between the variables can be determined by least squares. Estimated largest diameter in a stand is then determined for each stand diameter within the range of the field data:

Average stand d. b. h.	Largest d. b. h. in stand
(Inches)	
2.5	4.0
2.6	4.1
2.7	4.3
2.8	4.5
2.9	4.6
3.0	4.8
3.1	4.9
3.2	5.1
3.3	5.2
3.4	5.4
3.5	5.5
3.6	5.7
3.7	5.8
3.8	6.0
3.9	6.2
4.0	6.3

Stand Tables

Tree tallies from the unthinned plots were converted to cumulative stand tables. Procedure for construction of the stand tables was as follows:

1. Numbers of trees in each 1-inch diameter class of each plot were converted to cumulative frequencies in percent (Bruce and Schumacher 1950, p. 212).
2. Cumulative frequencies were plotted over stand diameter, with a separate curve for each diameter class. The 100-percent points of the plot data were replaced by previously computed estimates of the largest diameter in a stand (tabulation above). In all cases, the new 100-percent points fell on the trend lines established by the 80- to 99-percent values of each diameter class.
3. Subdivisions of the data were compared to determine if the distribution of frequencies varied within a stand diameter class because of stand density or site quality. No such trends could be established, so all data were treated as a single sample.
4. Cumulative frequencies in percent were read from each curve and tabulated for ready reference during yield table construction (see table 3).

Periodic Diameter Increase

Values from the plot description sheets (fig. 2) were used in multiple regression analysis to obtain an equation for estimating present stand diameter from past stand diameter. Variables in the final equations were then relabeled so that past became present and present became future. The equation thus predicts stand diameter in 10 years when present diameter and other descriptive data are known.

Stand diameter of Black Hills ponderosa pine 10 years in the future can be estimated from the relationship:

$$D_F = 1.0097\, D_P + 0.0096\, S - 1.5766 \log B_P + 3.3021$$

where
D_F = stand diameter in 10 years, in inches.
D_P = present stand diameter, in inches.
S = plot site index.
B_P = present basal area per acre, in square feet.

This working tool is applicable to even-aged stands with stocking levels of 50 to 170 (table 2) at the beginning of the 10-year prediction period. Ranges of the original field data were:
D_P, 3.4 to 16.3 inches
S, 37 to 73 feet
B_P, 48 to 150 square feet.
Examination of the differences between actual and computed plot diameters indicated that some extrapolation is possible beyond the limits of the data.

Diameter Increase from Thinning

There are two types of thinning from below, each of which causes stand diameter to increase without actual tree growth. An increase in average diameter accompanies the abrupt reduction in stand density caused by initial thinning. A lesser increase occurs when a stand is rethinned to the same stocking level to which density was reduced one or more times previously.

Rethinning a Black Hills ponderosa pine stand to the same stocking level it had 10 years previously results in an increase in average stand diameter of 0.4 inch. No relationship could be found between amount of increase and stocking level (range 70 to 120) or initial diameter (range 5.0 to 17.5 inches). Actual increase in any one stand will depend on the condition and arrangement (therefore need for cutting) of the largest trees. An increase of 0.4 inch was average for conditions present on the 24 plots examined.

Effect of rethinning is most conveniently determined by simulated marking of growth-prediction plots. Plot boundaries are marked so the plots can be relocated after past basal area, diameter, and stocking level have been computed and found to be within desired limits.

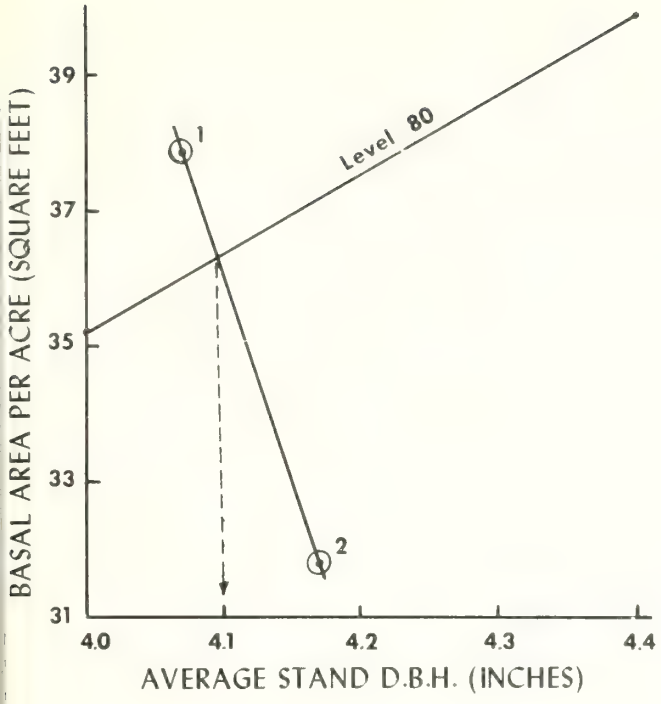
Change in stand diameter because of initial thinning can be determined by marking previously unthinned young stands. Plots established for other purposes (such as stand tables) can be used to get additional use from the field measurements and computations. Marking to all stocking levels of interest can be simulated on each plot and new average diameters determined. Data from thinning studies or administrative thinnings may be added to the sample where such cutting was to suitable stocking levels.

Because of the numerous possible combinations of initial stand density, desired stocking level, and initial stand diameter, the procedure of trial marking of sample plots was extended to provide a more convenient tool for estimation of diameter changes due to initial thinning. Most of the procedure is best carried out on electronic computers, but is described here as though done manually. Numerical examples refer to table 6 and figure 5.

1. Prepare a stand table for the stand, using the average stand diameter expected just before thinning (see "Stands Prior to Thinning") and the appropriate cumulative frequencies (table 3).
2. Assemble cards equal in number to the number of live trees before thinning (1680 in table 6) and label each card with a diameter so that the group of cards reproduces the stand table: 91 cards with "0", 240 cards with "1", and so forth.
3. Shuffle the cards so they become arranged in random order.
4. Estimate the number of trees to be retained per acre (400), and divide the number of original trees by the number of reserve trees, 1,680/400 = 4 (approx.).
5. Beginning with the first card and maintaining the original random order, divide the pile of cards into as many smaller piles as the number of reserve trees per acre. Each small pile, except perhaps the last one, will contain the number of cards determined by the quotient of the previous step.

Table 3.--Stand tables for young, unthinned Black Hills ponderosa pine.
(Numbers of trees expressed as cumulative frequencies in percent.)

Upper d.b.h. limit (Inches)	Average d.b.h. of stand (Inches)															
	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0
	Percent															
0.9	16.5	14.9	13.3	11.7	10.1	8.6	7.0	5.4	3.8	2.5	1.3	0.2	0	0	0	0
1.9	43.3	39.9	36.6	33.2	29.8	26.5	23.1	19.7	16.4	13.0	10.0	7.5	5.4	3.7	2.3	1.1
2.9	74.9	71.2	67.5	63.8	60.0	56.3	52.7	48.9	44.9	40.8	36.8	32.7	28.7	24.6	20.5	16.5
3.9	98.3	96.6	94.6	92.5	90.2	87.7	85.1	82.2	79.2	76.0	72.9	69.8	66.7	63.6	60.6	57.4
4.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.1	98.1	96.9	95.5	93.9	92.0	89.9	87.5	84.8
5.9								100.0	100.0	100.0	100.0	100.0	100.0	99.4	98.0	96.6
6.9														100.0	100.0	100.0



$N = 1680$ $\bar{D} = 3.2$

D	CUMUL PCT	CUMUL TREES	TREES
0-0.9	5.4	91	91
1-1.9	19.7	331	240
2-2.9	48.9	822	491
3-3.9	82.2	1381	559
4-4.9	99.1	1665	284
5-5.9	100.1	1680	15

Largest = 5.1

1:4 1:5

	Point 1	Point 2
Trees	420	336
BA	37.9	31.8
Dbh	4.07	4.17

Figure 5.--Determination of average d.b.h. after thinning. Site index 40, age 30. (See table 6.)

6. Tally the value of the largest diameter in each small pile. This produces an estimate of the stand table after thinning. Steps 3 to 6 may be repeated and the two estimated stand tables averaged to produce a single estimate.
7. Multiply the number of trees in each diameter class of the stand table by the basal area of the class midpoint. Use the estimated upper limit of the largest diameter class (tabulation, p. 9) to determine its class midpoint. Total the products to obtain basal area per acre.
8. Divide basal area by number of trees, and determine the diameter (to 0.01 inch) equivalent to this average basal area.
9. Plot a portion of the appropriate column of table 2, as shown in figure 5, for stocking level 80.
10. Plot basal area (step 7) over average diameter (step 8) on the graph of step 9, as done for point 1 of figure 5.
11. Repeat steps 3 to 8 with a ratio (step 4) that will produce a point on the other side of the line of step 9, for example, 1:5. Plot basal area and average diameter of the stand table estimated by this step, as shown by point 2 of figure 5.
12. Draw a line between the two points plotted in steps 10 and 11. The point of intersection of this line with the stocking level line (step 9) is projected to the horizontal axis of the graph. The value read on this axis to 0.1 inch is expected stand diameter after thinning. Comparison of results obtained by this method with data from actual semipermanent plots indicated that the difference between actual and estimated diameters will frequently be 0.1 inch or less.

Periodic Basal Area Growth

Basal area per acre in 10 years can be estimated from the relationship:

$B_F = 0.9263\ B_P + 0.0006\ N \times S + 15.7887$

where

B_F = basal area per acre in 10 years, in square feet.

B_P = present basal area per acre in square feet.

N = present number of trees per acre.

S = site index in feet.

This equation may be used under the same conditions as the diameter growth equation given above.

Height of Dominants and Codominants

A record of heights attained at various ages was needed for later use in the computation of volumes. Height-age relationships were established for stands continuously free to grow in height, so that heights attainable by managed stands could be estimated. Heights attained by dominant and codominant trees were determined because they are far less affected by thinning from below than are average heights of all trees. Each site index class of interest was sampled so the effect of site quality on height growth could be determined.

Records of the growth-prediction plots (fig. 2) were sorted to identify those plots that probably had a history of normal height growth. The data were further sorted by 10-foot site index classes.

Average height of the dominant and codominant trees of each stand was plotted over stand age, with a separate set of points for each site index class. Smooth, balanced curves were drawn through each set of points, and heights at 10-year intervals were read from each curve (table 4). Where necessary, heights were adjusted to the site class midpoint by multiplying curve height by the proportion: (midpoint of site index class) ÷ (actual average site index of the data in the class).

Table 4. --Average height of dominant and codominant trees at various ages, Black Hills ponderosa pine

Main stand age (Years)	Site index class			
	40	50	60	70
	----- Feet -----			
10	4.5	4.5	4.5	4.5
20	9	10	12	16
30	11	16	20	26
40	17	22	28	35
50	21	28	35	43
60	26	33	41	50
70	30	38	47	56
80	34	43	52	61
90	37	47	57	66
100	40	50	60	70
110	43	53	63	74
120	45	56	66	77
130	46	59	69	80
140	48	61	71	83
150	50	63	73	86

Table 4 is very similar to table 1 of Technical Bulletin 630 (Meyer 1938). This suggests that heights from good site index curves may supplement or substitute for local data, if necessary. The site index curves must be based on the crown classes desired for yield table computations.

Stand Volume Equation

Cubic volumes per acre of Black Hills ponderosa pine can be estimated by the relationship:

$V = 0.4047\,B \times H + 25.5970\,D - 191.6433$

$R = 0.999$

$S_{xy} = 39.648$ (1.7% of mean)

where

V = gross volume per acre in cubic feet from ground line to tip of all trees more than 4.5 feet tall.

B = basal area per acre in square feet.

H = average height of dominant and codominant trees in feet.

D = average stand diameter in inches.

Data for determination of the regression constants were obtained from present volume, height, and diameter of each plot (fig. 2). Total cubic feet was used as the unit for projection because it does not vary with changes in standards of merchantability.

Volume Conversion Factors

Total cubic volumes were converted to other units of interest to the forest manager by means of conversion factors (table 5). Volumes from the plot summary records (fig. 2) were used to compute ratios that were plotted over stand diameter (Chapman and Meyer 1949, p. 384). Yields could also have been expressed as weight of dry wood if emphasis were on fiber production (Myers 1960).

Ratios were not computed for the smallest average stand diameters because the varia-

Table 5a. --Factors for conversion of stand volumes in total cubic feet to merchantable cubic feet per acre.[1]

Average stand diameter (Inches)	Ratio of merchantable to total volume	Average stand diameter (Inches)	Ratio of merchantable to total volume
5.0	0.332	11.0	0.935
5.2	.377	11.2	.936
5.4	.422	11.4	.937
5.6	.465	11.6	.938
5.8	.508	11.8	.939
6.0	.552	12.0	.940
6.2	.597	12.2	.941
6.4	.639	12.4	.942
6.6	.678	12.6	.942
6.8	.710	12.8	.943
7.0	.740	13.0	.944
7.2	.766	13.5	.947
7.4	.789	14.0	.949
7.6	.809	14.5	.951
7.8	.826	15.0	.953
		15.5	.955
8.0	.842		
8.2	.856	16.0	.956
8.4	.868	16.5	.957
8.6	.876	17.0	.958
8.8	.884	17.5	.959
		18.0	.960
9.0	.892	18.5	.961
9.2	.899		
9.4	.906	19.0	.962
9.6	.913	19.5	.963
9.8	.920	20.0	.964
		20.5	.965
10.0	.926	21.0	.966
10.2	.930	21.5	.966
10.4	.932		
10.6	.933	22.0	.967
10.8	.934		

[1] To 4.0-inch top in trees 6.0 inches d.b.h. and larger.

Table 5b. --Factors for conversion of stand volumes in total cubic feet to board feet per acre.[1]

Average stand diameter (Inches)	Ratio of board feet to total volume		Average stand diameter (Inches)	Ratio of board feet to total volume	
	Scribner	International 1/4 inch		Scribner	International 1/4 inch
11.0	1.52	1.81	14.0	4.06	4.88
11.2	1.71	2.04	14.5	4.30	5.14
11.4	1.91	2.27	15.0	4.44	5.30
11.6	2.10	2.51	15.5	4.58	5.44
11.8	2.30	2.74	16.0	4.72	5.57
			16.5	4.85	5.69
12.0	2.48	2.97	17.0	4.97	5.78
12.2	2.68	3.21	17.5	5.08	5.86
12.4	2.86	3.44			
12.6	3.04	3.66	18.0	5.17	5.93
12.8	3.21	3.86	18.5	5.26	5.99
			19.0	5.33	6.04
13.0	3.37	4.06	19.5	5.40	6.09
13.2	3.52	4.24	20.0	5.46	6.14
13.4	3.68	4.42	20.5	5.52	6.18
13.6	3.81	4.58	21.0	5.58	6.22
13.8	3.94	4.73	21.5	5.63	6.25
			22.0	5.68	6.28

[1] In trees 12.0 inches d.b.h. and larger to an 8-inch top.

bility of conversion factors increases as stand diameter decreases. Likewise, minimum diameter for sawtimber was set at 12 inches to further reduce variability among plots. Most ponderosa pines 12 inches in diameter contain at least one saw log; most 11-inch pines do not.

Absence of conversion factors for the smallest stand diameters has no effect on yield table construction. An occasional entry for merchantable cubic feet or board feet will be missing when salable material is obviously present. No information is lost because salable material will not be a part of thinnings until stand diameter is large enough for conversion factors to be reliable.

Other ways of determining salable volume, such as stand volume equations, were tested for Black Hills ponderosa pine. No method tried was as satisfactory as conversion of total cubic volume.

Derivation of Yield Tables

The working tools described above were used to derive two sets of yield tables for ponderosa pine in the Black Hills. The tables indicate potential productivity of managed stands for the site qualities and management goals selected. Site index classes 40, 50, 60, and 70 (base age 100 years) and stocking levels 80 and 100 describe the range of site quality in the Black Hills and stocking appropriate for the site quality.

The first four tables (tables 6, 7, 8, and 9) give volume and other information on the assumption that cutting interval is 10 years. These tables are useful in such computations as determination of culmination of mean annual increment. They are similar in form to normal yield tables, but apply to managed stands.

The second group of tables (tables 10, 11, 12, and 13) illustrates what growth in actual stands may be if the interval between cuts is 20 years. One more management decision, the cutting cycle, is thus introduced into the computations.

Table 6.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills
Site index 40, 10-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchantable volume	Sawtimber volume	Trees	Basal area	Total volume	Merchantable volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,680	94	3.2	11	310	--	--	320				
30	397	36	4.1	11	80	--	--	1,283	58	230	0	0
40	397	63	5.4	17	380	170	--					
40	298	55	5.8	17	330	170	--	99	8	50	0	0
50	298	75	6.8	21	620	440	--					
50	237	67	7.2	21	560	430	--	61	8	60	10	0
60	237	85	8.1	26	910	770	--					
60	191	75	8.5	26	820	710	--	46	10	90	60	0
70	191	90	9.3	30	1,140	1,030	--					
70	155	80	9.7	30	1,020	940	--	36	10	120	90	0
80	155	93	10.5	34	1,360	1,270	--					
80	123	80	10.9	34	1,190	1,110	--	32	13	170	160	0
90	123	92	11.7	37	1,480	1,390	3,400					
90	100	80	12.1	37	1,320	1,240	3,400	23	12	160	150	0
100	100	91	12.9	40	1,610	1,520	5,300					
100	83	80	13.3	40	1,440	1,370	5,200	17	11	170	150	100
110	83	90	14.1	43	1,740	1,650	7,100					
110	70	80	14.5	43	1,570	1,490	6,800	13	10	170	160	300
120	70	89	15.3	45	1,830	1,740	8,300					
120	60	80	15.7	45	1,670	1,590	7,700	10	9	160	150	600
130	60	89	16.5	46	1,890	1,810	9,200					
130	51	80	16.9	46	1,730	1,660	8,600	9	9	160	150	600
140	51	87	17.7	48	1,950	1,880	10,000					

Table 7.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills
Site index 50, 10-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchantable volume	Sawtimber volume	Trees	Basal area	Total volume	Merchantable volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,600	101	3.4	16	550	--	--	400				
30	384	39	4.3	16	170	--	--	1,216	62	380	0	0
40	384	66	5.6	22	540	260	--					
40	288	57	6.0	22	470	260	--	96	9	70	0	0
50	288	79	7.1	28	890	670	--					
50	225	69	7.5	28	780	630	--	63	10	110	40	0
60	225	89	8.5	33	1,210	1,060	--					
60	178	77	8.9	33	1,070	950	--	47	12	140	110	0
70	178	93	9.8	38	1,490	1,370	--					
70	141	80	10.2	38	1,300	1,210	--	37	13	190	160	0
80	141	95	11.1	43	1,740	1,630	3,000					
80	111	80	11.5	43	1,490	1,400	3,000	30	15	250	230	0
90	111	93	12.4	47	1,900	1,790	5,400					
90	90	80	12.8	47	1,660	1,560	5,300	21	13	240	230	100
100	90	92	13.7	50	2,020	1,920	7,800					
100	74	80	14.1	50	1,790	1,700	7,300	16	12	230	220	500
110	74	91	15.0	53	2,140	2,040	9,500					
110	62	80	15.4	53	1,920	1,830	8,700	12	11	220	210	800
120	62	90	16.3	56	2,260	2,160	10,900					
120	53	80	16.7	56	2,050	1,960	10,000	9	10	210	200	900
130	53	90	17.6	59	2,400	2,300	12,200					
130	45	80	18.0	59	2,180	2,090	11,300	8	10	220	210	900
140	45	89	19.0	61	2,480	2,390	13,200					

Table 8. --Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills
Site index 60, 10-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchantable volume	Sawtimber volume	Trees	Basal area	Total volume	Merchantable volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,550	110	3.6	20	790	--	--	450				
30	371	41	4.5	20	260	--	--	1,179	69	530	0	0
40	371	70	5.9	28	760	400	--					
40	274	59	6.3	28	640	400	--	97	11	120	0	0
50	274	82	7.4	35	1,160	910	--					
50	215	71	7.8	35	1,020	840	--	59	11	140	70	0
60	215	91	8.8	41	1,540	1,360	--					
60	169	78	9.2	41	1,340	1,210	--	46	13	200	150	0
70	169	96	10.2	47	1,890	1,760	--					
70	131	80	10.6	47	1,600	1,490	--	38	16	290	270	0
80	131	96	11.6	52	2,130	2,000	4,500					
80	102	80	12.0	52	1,800	1,690	4,500	29	16	330	310	0
90	102	94	13.0	57	2,310	2,180	7,800					
90	82	80	13.4	57	2,000	1,890	7,300	20	14	310	290	500
100	82	93	14.4	60	2,430	2,310	10,300					
100	67	80	14.8	60	2,130	2,030	9,300	15	13	300	280	1,000
110	67	91	15.8	63	2,540	2,430	11,900					
110	56	80	16.2	63	2,260	2,160	10,800	11	11	280	270	1,100
120	56	90	17.2	66	2,660	2,550	13,300					
120	47	80	17.6	66	2,400	2,300	12,200	9	10	260	250	1,100
130	47	89	18.6	69	2,760	2,650	14,600					
130	41	80	19.0	69	2,530	2,430	13,500	6	9	230	220	1,100
140	41	90	20.1	71	2,920	2,810	16,000					

Table 9. --Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills
Site index 70, 10-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchantable volume	Sawtimber volume	Trees	Basal area	Total volume	Merchantable volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,480	117	3.8	26	1,130	--	--	520				
30	458	53	4.6	26	480	--	--	1,022	64	650	0	0
40	458	87	5.9	35	1,190	630	--					
40	343	74	6.3	35	1,020	630	--	115	13	170	0	0
50	343	102	7.4	43	1,780	1,410	--					
50	268	89	7.8	43	1,560	1,290	--	75	13	220	120	0
60	268	113	8.8	50	2,320	2,050	--					
60	212	98	9.2	50	2,020	1,820	--	56	15	300	230	0
70	212	118	10.1	56	2,740	2,540	--					
70	166	100	10.5	56	2,340	2,190	--	46	18	400	350	0
80	166	118	11.4	61	3,010	2,820	5,900					
80	132	100	11.8	61	2,580	2,420	5,900	34	18	430	400	0
90	132	116	12.7	66	3,230	3,050	10,100					
90	107	100	13.1	66	2,810	2,660	9,700	25	16	420	390	400
100	107	114	14.0	70	3,410	3,230	13,800					
100	88	100	14.4	70	3,010	2,860	12,800	19	14	400	370	1,000
110	88	114	15.4	74	3,610	3,450	16,400					
110	73	100	15.8	74	3,210	3,070	15,000	15	14	400	380	1,400
120	73	112	16.8	77	3,740	3,580	18,400					
120	62	100	17.2	77	3,360	3,220	16,900	11	12	380	360	1,500
130	62	112	18.2	80	3,900	3,740	20,300					
130	53	100	18.6	80	3,520	3,380	18,600	9	12	380	360	1,700
140	53	111	19.6	83	4,040	3,890	21,900					

Table 10.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills

Site index 40, 20-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchantable volume	Sawtimber volume	Trees	Basal area	Total volume	Merchantable volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,680	94	3.2	11	310	--	--	320				
30	397	36	4.1	11	80	--	--	1,283	58	230	0	0
50	397	86	6.3	21	700	430	--					
50	257	63	6.7	21	510	360	--	140	23	190	70	0
70	257	99	8.4	30	1,220	1,060	--					
70	182	77	8.8	30	960	850	--	75	22	260	210	0
90	182	105	10.3	37	1,650	1,540	--					
90	128	80	10.7	37	1,280	1,200	--	54	25	370	340	0
110	128	104	12.2	43	1,930	1,810	5,200					
110	92	80	12.6	43	1,520	1,430	4,600	36	24	410	380	600
130	92	100	14.1	46	2,030	1,920	8,300					
130	20	29	16.4	46	770	740	3,000	72	71	1,260	1,180	5,300
140	20	35	17.9	48	950	910	4,200	20	35	950	910	4,200
Total								2,000	258	3,670	3,090	10,100

Table 11.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills

Site index 50, 20-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchantable volume	Sawtimber volume	Trees	Basal area	Total volume	Merchantable volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,600	101	3.4	16	550	--	--	400				
30	384	39	4.3	16	170	--	--	1,216	62	380	0	0
50	384	91	6.6	28	1,010	690	--					
50	245	66	7.0	28	730	540	--	139	25	280	150	0
70	245	103	8.8	38	1,630	1,440	--					
70	169	78	9.2	38	1,250	1,120	--	76	25	380	320	0
90	169	110	10.9	47	2,170	2,030	2,900					
90	115	80	11.3	47	1,620	1,520	2,900	54	30	550	510	0
110	115	106	13.0	53	2,410	2,280	8,100					
110	82	80	13.4	53	1,870	1,770	6,900	33	26	540	510	1,200
130	82	102	15.1	59	2,630	2,510	11,800					
130	18	30	17.5	59	980	940	4,300	64	72	1,650	1,570	7,500
140	18	36	19.1	61	1,180	1,140	5,600	18	36	1,180	1,140	5,600
Total								2,000	276	4,960	4,200	14,300

Table 12.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills

Site index 60, 20-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchantable volume	Sawtimber volume	Trees	Basal area	Total volume	Merchantable volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,550	110	3.6	20	790	--	--	450				
30	371	41	4.5	20	260	--	--	1,179	69	530	0	0
50	371	96	6.9	35	1,350	980	--					
50	233	68	7.3	35	950	740	--	138	28	400	240	0
70	233	110	9.3	47	2,140	1,930	--					
70	155	80	9.7	47	1,570	1,440	--	78	30	570	490	0
90	155	114	11.6	57	2,730	2,560	5,700					
90	102	80	12.0	57	1,960	1,840	4,900	53	34	770	720	800
110	102	107	13.9	63	2,900	2,760	11,600					
110	72	80	14.3	63	2,210	2,100	9,300	30	27	690	660	2,300
130	72	103	16.2	69	3,100	2,970	14,800					
130	16	30	18.6	69	1,130	1,080	5,200	56	73	1,970	1,890	9,600
140	16	36	20.3	71	1,360	1,310	6,800	16	36	1,360	1,310	6,800
Total								2,000	297	6,290	5,310	19,500

Table 13.--Yields per acre of managed, even-aged stands of ponderosa pine in the Black Hills

Site index 70, 20-year cutting cycle

Stand age (Yrs.)	Entire stand before and after thinning							Periodic cut and mortality				
	Trees	Basal area	Average d.b.h.	Average height	Total volume	Merchantable volume	Sawtimber volume	Trees	Basal area	Total volume	Merchantable volume	Sawtimber volume
	No.	Sq.ft.	In.	Ft.	Cu.ft.	Cu.ft.	Bd.ft.	No.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
10	2,000			5								
30	1,480	117	3.8	26	1,130	--	--	520				
30	458	53	4.6	26	480	--	--	1,022	64	650	0	0
50	458	119	6.9	43	2,050	1,490	--					
50	291	85	7.3	43	1,470	1,140	--	167	34	580	350	0
70	291	131	9.1	56	3,020	2,700	--					
70	201	99	9.5	56	2,290	2,080	--	90	32	730	620	0
90	201	138	11.2	66	3,770	3,530	6,400					
90	136	100	11.6	66	2,780	2,600	5,800	65	38	990	930	600
110	136	131	13.3	74	4,080	3,860	14,700					
110	98	100	13.7	74	3,150	2,990	12,200	38	31	930	870	2,500
130	98	130	15.6	80	4,420	4,220	20,400					
130	17	31	18.2	80	1,270	1,220	5,900	81	99	3,150	3,000	14,500
140	17	37	20.0	83	1,570	1,510	7,900	17	37	1,570	1,510	7,900
Total								2,000	335	8,600	7,280	25,500

Steps in the derivation of yield tables with 10-year cutting intervals were as follows:

1. Forms with the headings shown in tables 6 to 13 were prepared for each combination of site index and growing stock level of interest. Two values were entered for each age, beginning with age at initial thinning. The first age of each pair identified conditions just prior to thinning; the second age identified conditions immediately after thinning.
2. Diameters, basal areas, and numbers of trees were recorded for stands prior to thinning at age 30. Number of trees and stand diameter were chosen as the starting point of projections, as described in the section "Initial Management Decisions." Basal area before thinning was the product of number of trees times the basal area corresponding to stand diameter.
3. Average heights of dominant and codominant trees (table 4) were recorded in the appropriate spaces in the fifth column of each yield table. Both heights at any age were considered to be equal, because thinning from below was expected to have minor effect on average dominant and codominant height.
4. Stand diameter after initial thinning to the prescribed growing stock level was determined by procedures described in the "Computations" section.
5. Basal area corresponding to stand diameter after thinning was obtained from table 2 in the column headed by the appropriate stocking level designation. Portions of the appropriate column of table 2 were graphed where table interpolation was to be avoided.
6. Number of trees after thinning at age 30 was computed by dividing basal area per acre from table 2 by the basal area equivalent to the stand diameter.
7. Stand diameter was projected from after thinning at age 30 to before thinning at age 40 by means of the diameter growth equation. Projections could have been made with either the diameter growth equation or the basal area equation. Diameter projections were used because most steps in procedure used diameter as an important independent variable, and the diameter equation appeared to be better than the basal area equation. Mathematical relationships between numbers of trees, basal area, and average diameter will not correspond exactly if both equations are used together. Both equations are subject to error, and diameter, basal area, and number of trees would balance only by chance.
8. Number of trees before thinning at age 40 was considered to be the same as the number after thinning at age 30. Examination of numerous stands and semipermanent plots in the Black Hills indicated that noncatastrophic mortality is slight or absent in the stands of rather low density expected under management. This was especially true where the stands were of relatively low density before thinning, and spindly, undesirable trees were not so numerous as to form part of the residual stand. Losses from fire, insect epidemic, and so forth, are best handled as reductions from yield table values.
9. Basal area before thinning at age 40 was computed by multiplying number of trees by the basal area corresponding to stand diameter.
10. Stand diameter after thinning at age 40 was obtained by adding 0.4 inch to diameter before thinning, as described in "Diameter Increase from Thinning."
11. Basal area after thinning at age 40 was obtained from table 2 for the diameter computed in step 10 and for the appropriate stocking level.
12. Number of trees after thinning at age 40 was computed by dividing basal area per acre by the basal area equivalent to the stand diameter.
13. Steps 8 to 13 were repeated until the desired maximum stand age was reached, in this case 140 years. Once stand diameter reached 10.0 inches, basal area after thinning was always equal to the growing stock level for which the yield table was made (80 and 100 in the examples).
14. The basal area growth equation was used to be sure that each periodic change in basal area shown in the yield tables was reasonable. All differences between basal areas from diameter projection and from the growth equations were less than the standard error of the basal area growth equation, 4.3 square feet.
15. The stand volume equation was used to compute total cubic feet per acre before and after thinning.

16. Total cubic volumes were converted to merchantable cubic feet and to board feet Scribner Rule by means of the appropriate conversion factors (table 5).
17. Basal areas and volumes were rounded off to remove unnecessary decimals and units that had been retained during computations and checking.
18. Amounts of periodic cut and mortality were obtained for ages after initial thinning. At any given age, values after thinning were subtracted from corresponding values before thinning. No attempt was made to estimate the volume and basal area of trees that died before initial thinning. Stand density will not be definite and predictable until control is imposed by thinning.

Yield tables for cutting intervals of 20 years (tables 10-13) were derived with almost the same procedures described above. Differences in procedure were as follows:

1. Stand diameter was projected from age 30 to age 40, as above. Stand conditions at age 40 were then used to determine stand diameter at age 50, with no changes due to thinning at age 40. Other periods were handled in a similar manner.
2. Regeneration by two-cut shelterwood was shown at the end of the rotation. Length of the period between seed cut and final cut was set at 10 years. Necessary length of this period has not yet been established for the Black Hills, and this computation is intended only as an example of yield table construction. Board-foot volumes were reduced about 700 board feet per acre to compensate for the extreme truncation of diameter distributions produced by shelterwood cutting.

Projections for 20 years could have been obtained from an equation based on 20 years' growth. Tests indicated that results from two projections by the 10-year equation were equally good as one projection by a 20-year equation.

Ratios of basal area, and other adjustments such as used to obtain approximations of growth from normal yield tables, are unnecessary with the procedure described here. Actual stand conditions are used as the beginning point of projections, even if they depart from the "standards" shown in tables 6 to 13. The only requirement is that the stand values be within the limits of the data used to establish the growth equations and other relationships.

Comparison with Other Results

Most results presented here cannot be compared with the response of trees on permanent plots in the Black Hills. Records of changes in 10 years are not available for plots cut to density levels near possible management goals. Plots cut to desirable levels but remeasured at longer intervals than 10 years show good agreement between actual and computed values, if the necessary interpolations are accepted as correct. A few sawtimber stands that appear to have never suffered reduced growth because of high density exist in the Black Hills. Present average diameter, volume, and age of these stands indicate that the estimates shown in the yield tables are reasonable.

In the absence of local growth comparisons from permanent plots, 32 sets of data were obtained from permanent plots in even-aged ponderosa pine in Arizona, Washington, Oregon, Montana, and Idaho.[3] The discussion that follows is based on these data.

Repeated projections by growth equations could lead to unsatisfactory results if the changes indicated by the equations were biased. The diameter growth equation was checked for bias by the use of permanent-plot data. This comparison also provides an indication of the relative value of data from temporary and permanent plots. Differences between actual and computed future diameters, and the percentage of plots with each difference, were as follows:

[3] *Cooperation of personnel of the Intermountain and Pacific Northwest Forest and Range Experiment Stations, U. S. Forest Service, in supplying data from their areas is gratefully acknowledged.*

Actual minus estimated	Distribution of plots	
	Temporary	Permanent
(Inches)	(Percent)	
-0.3	7	3
-.2	9	12
-.1	19	19
0	28	22
+.1	20	25
+.2	10	16
+.3	7	3

Differences were equal in range and similar in distribution for the two types of plot. Symmetry of the residuals from the temporary plots was expected because these plots supplied the data for the least-squares solution of the growth equation.

Temporary and permanent plots provided growth and yield data similar in numerical values and in degree of variability. There is no reason to deny forest managers the guidance of yield information until such time as permanent plots have been installed, measured, and analyzed.

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Presents procedures for deriving yield tables for managed stands from data obtained on temporary plots. Yield tables for Black Hills ponderosa pine are given as examples of procedure.

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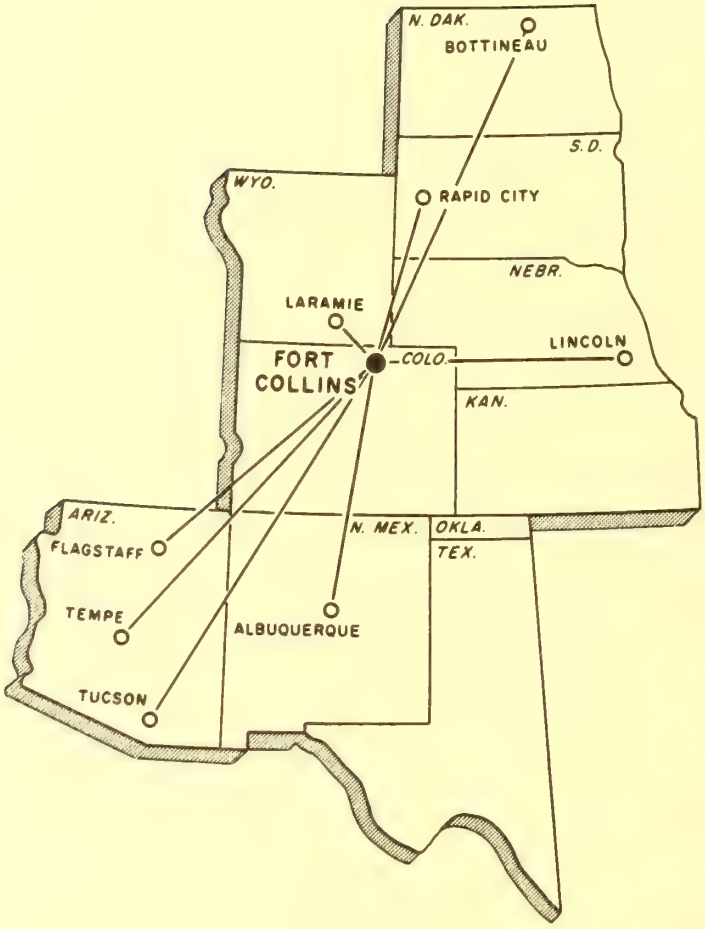
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THE SANTA RITA EXPERIMENTAL RANGE

A Center for Research on Improvement and Management of Semidesert Rangelands

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COOPERATORS

Many agencies and individuals cooperate in conducting research on the Santa Rita Experimental Range. Among those currently involved are:

The University of Arizona
Agricultural Research Service
Soil Conservation Service
Bureau of Sport Fisheries and Wildlife
Arizona Department of Game and Fish
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THE SANTA RITA EXPERIMENTAL RANGE

A Center for Research on Improvement and Management of Semidesert Rangelands

by

S. Clark Martin, Principal Range Scientist

Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained in cooperation with Colorado State University at Fort Collins; author is located at Tucson in cooperation with the University of Arizona.

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THE SANTA RITA EXPERIMENTAL RANGE

A Center for Research on Improvement and Management of Semidesert Rangelands

S. Clark Martin

DESCRIPTION OF THE RANGE

The Santa Rita Experimental Range, 30 miles south of Tucson, Arizona is maintained by the Forest Service, U.S. Department of Agriculture, for research on semidesert ranges grazed by cattle. The 50,000-acre Experimental Range, established in 1903, is representative of about 20 million acres of semidesert grass-shrub range in southern Arizona, New Mexico, and Texas (fig. 1). Research is conducted in cooperation with State and other Federal agencies, and with cooperating cattlemen.

The Range lies on a broad, sloping plain cut by many shallow, dry washes. The elevation rises from less than 2,900 feet at the northwest corner to over 4,500 feet along the foothills of the Santa Rita Mountains.

CLIMATE

Average yearly rainfall increases with elevation from 10 inches at 2,900 feet to almost 20 inches at 4,300 feet (fig. 2). About 60 percent of the rain comes between July 1 and September 30 (fig. 3). No effective rainfall is expected in April, May, or June.

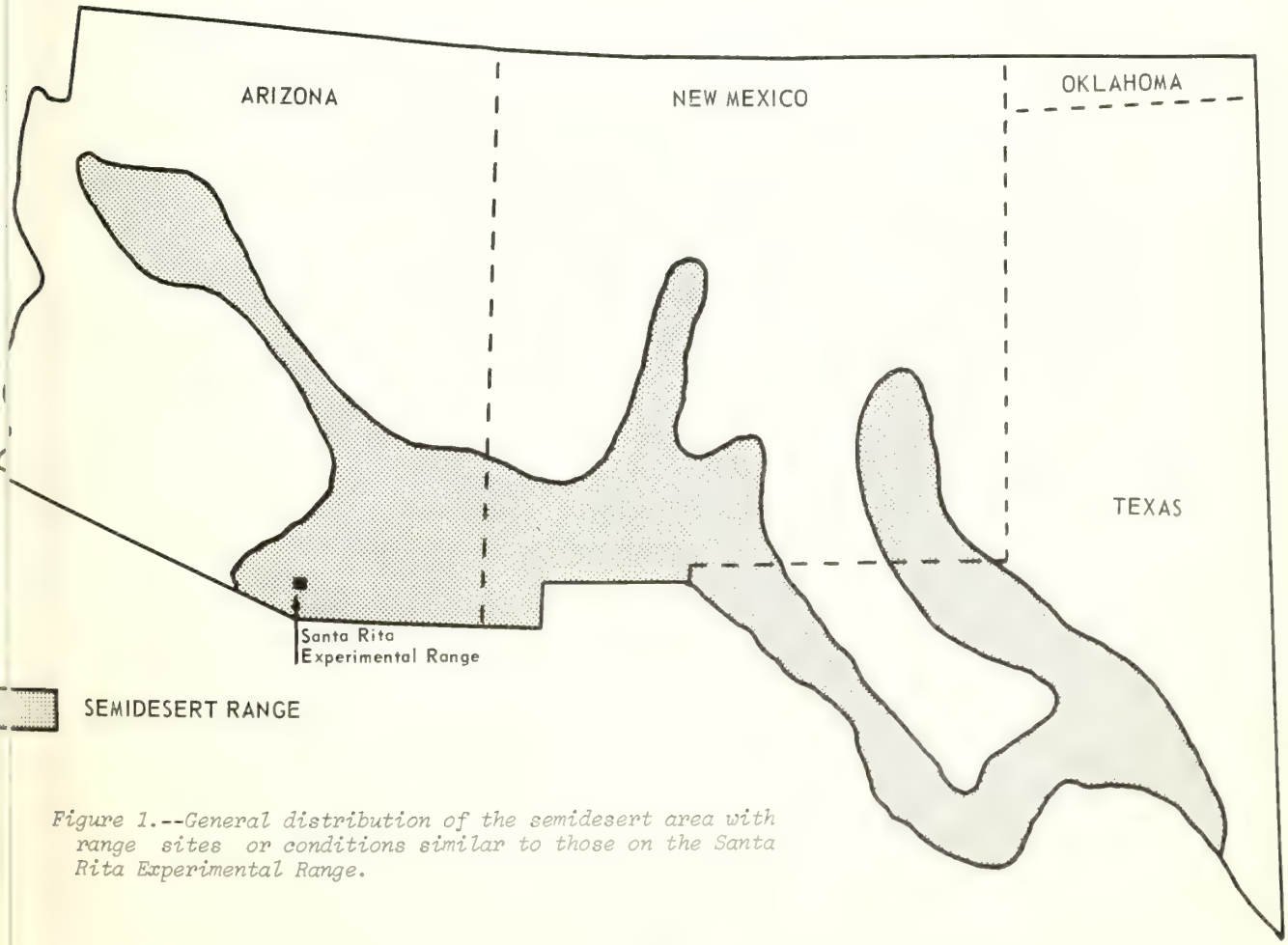


Figure 1.--General distribution of the semidesert area with range sites or conditions similar to those on the Santa Rita Experimental Range.

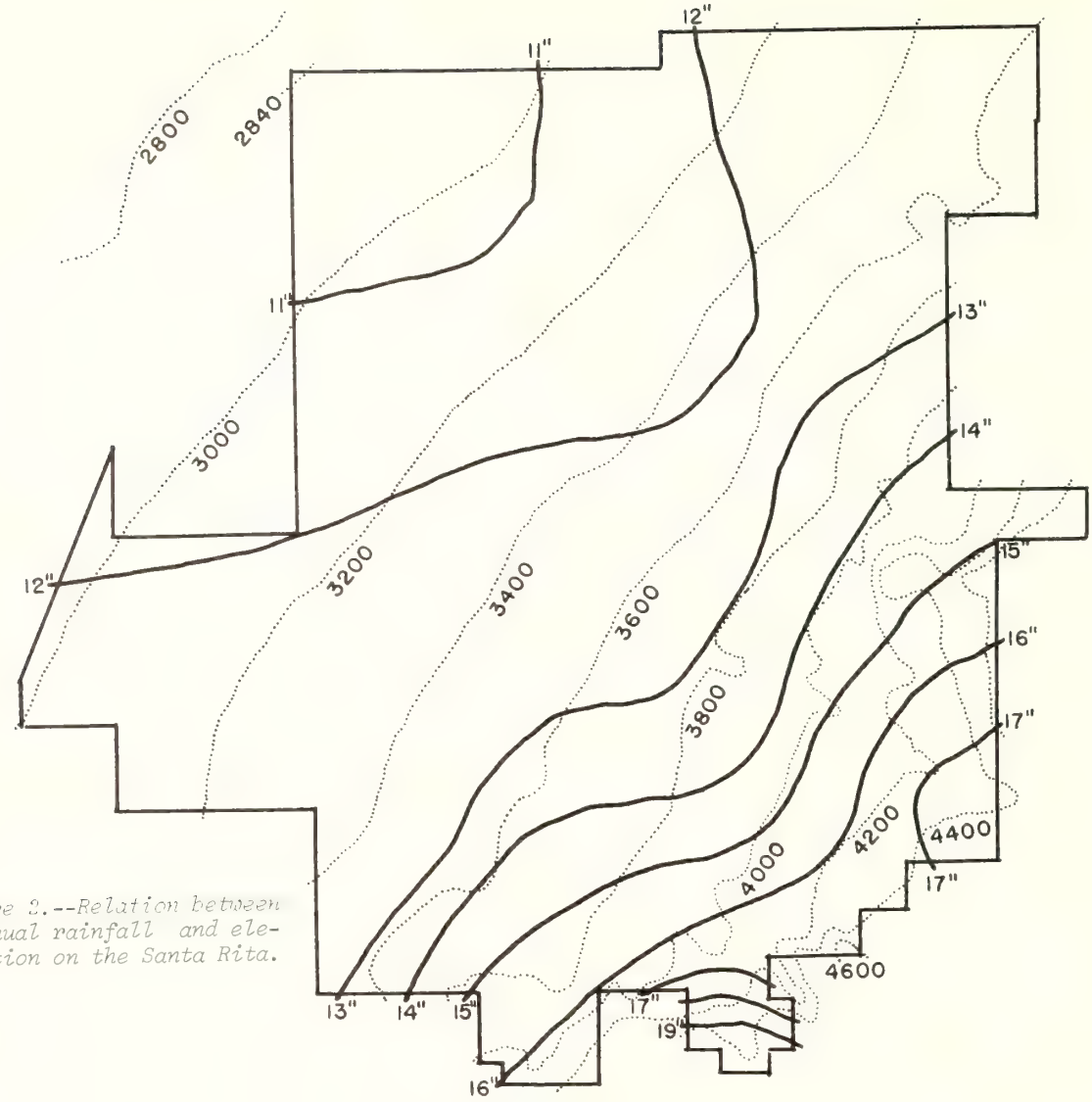


Figure 2.--Relation between annual rainfall and elevation on the Santa Rita.

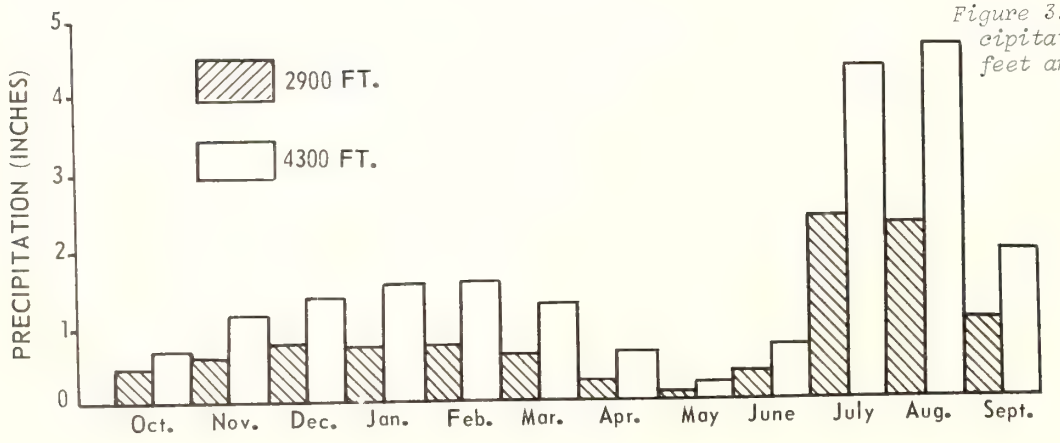


Figure 3.--Monthly precipitation at 4,300 feet and 2,900 feet.

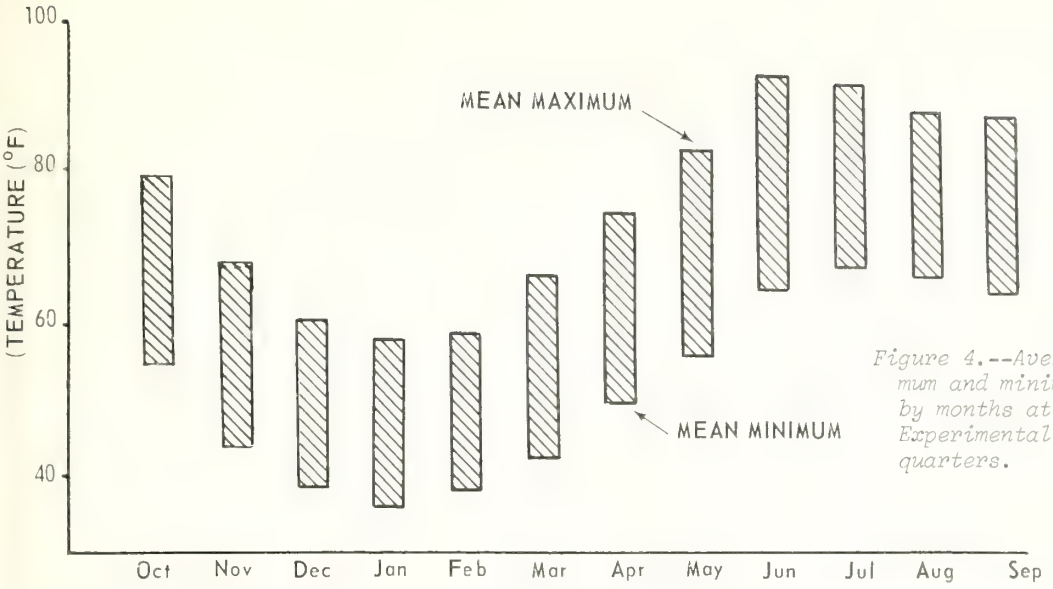


Figure 4.--Average daily maximum and minimum temperatures by months at the Santa Rita Experimental Range Headquarters.

Average daily maximum temperatures at the Range headquarters exceed 90° F. in June and July. Daily mimimum temperatures average below 40° F. in December, January, and February (fig. 4). The frost-free period is about 8 months, but growth of herbaceous plants usually is limited by lack of moisture to about 8 weeks.

VEGETATION

The perennial vegetation is dominated by mesquite,[2] cactus, and other shrubs. Mesquite, burroweed, and cholla cactus reach their highest average densities between 3,200 and 3,600 feet elevation (fig. 5); mesquite and pricklypear cactus are major species even above 4,000 feet. Other shrubs, including **Acacia, Mimosa,** and **Calliandra,** make up only 21 percent of the shrub cover below 3,200 feet but comprise 65 percent of the shrub cover above 4,000 feet.

[2]*Common and scientific names of plants mentioned are listed on page 24.*

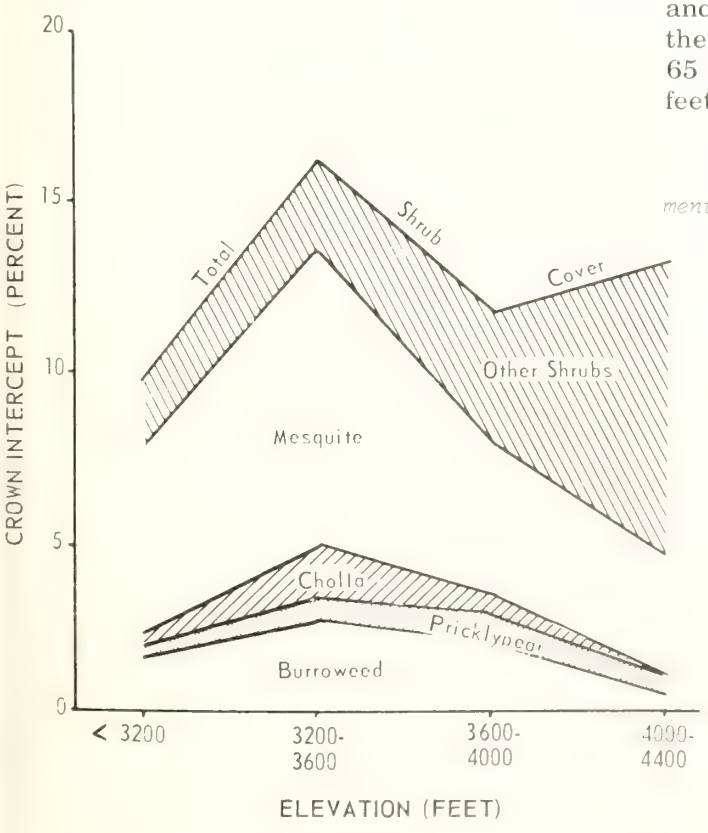


Figure 5.--Crown cover of major shrub species and total shrub cover as a function of elevation.

The abundance of perennial grasses increases with rainfall and elevation (fig. 6). The species composition of the perennial grass stand also changes with elevation and rainfall. The tall three-awns are common at all elevations (fig. 7). Santa Rita three-awn, Arizona cottontop, and Rothrock grama are major species at the middle and lower elevations but are minor species above 4,000 feet. Bush muhly makes up a greater part of the grass stand at the lower than at the middle elevations, and is scarce at the upper elevations. Other gramas including black, side-oats, slender, sprucetop, and hairy, make up over 60 percent of the stand at the upper elevations and are relatively scarce at the middle and lower elevations.

RESEARCH

The objective is to learn how to attain maximum sustained forage and beef production on semidesert range with reasonable costs. The research program includes many kinds of studies. Most important of all is research to develop grazing practices that meet the long-time needs of the forage plants and the soil, as well as the immediate needs of the cattle and the rancher. Detailed studies of the growth requirements of desirable and undesirable range plants and their reactions to various kinds of grazing, climate, and soil are basic. Learning how to improve rundown ranges rapidly and economically by controlling unwanted plants, reseeding, or other cultural practices is another important area of research.

The Federal government owns the land and improvements; cattle for grazing experiments are furnished by private ranchers operating under cooperative agreements. The cattlemen furnish the kind, number, and class of cattle needed, and manage them according to a written management plan. Under this arrangement, grazing studies are carried out on a practical scale, thereby eliminating the need for pilot testing.

Figure 6.--
Vegetation on the Santa Rita Experimental Range at:

Upper elevation

Intermediate elevation

Lower elevation

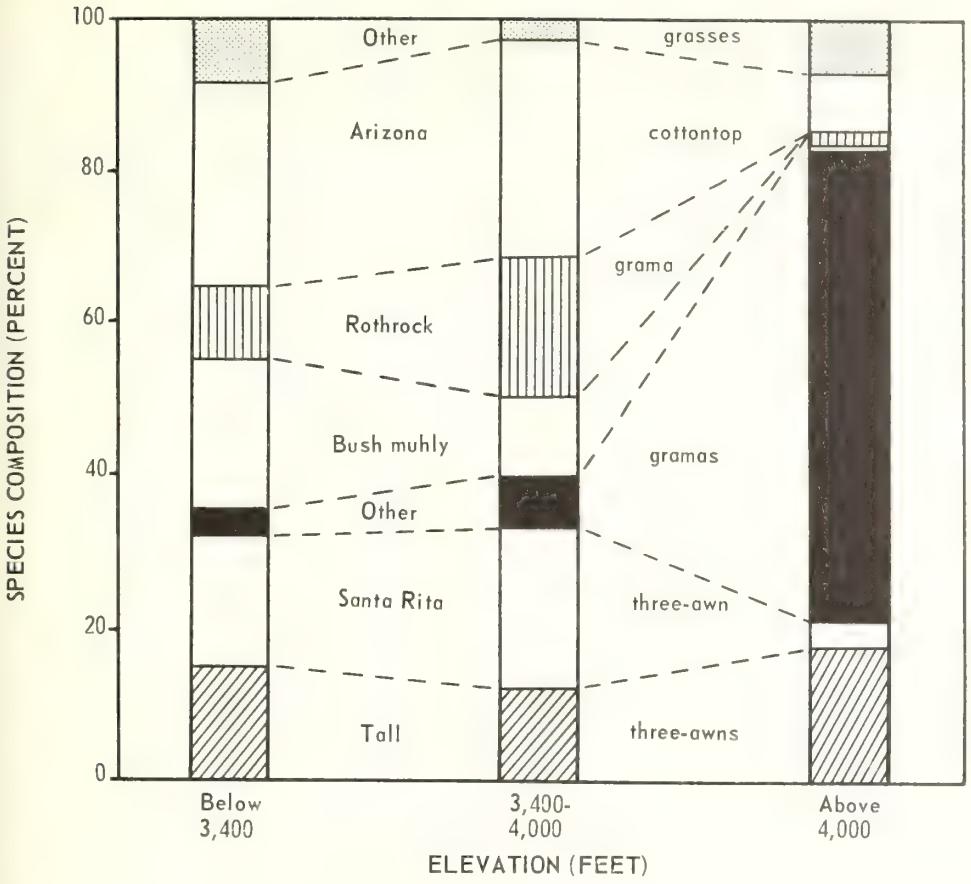


Figure 7.--Relative abundance of perennial grass species at different elevations in June 1960.

FORAGE PRODUCTION

Rainfall during both summer and winter makes possible two growth periods—a minor one during early spring when temperatures become favorable, and the major one during summer when rains begin after the late spring drought. Perennial grasses, browse, and annuals each react to this climate with their own characteristic growth pattern.

Perennial grasses are the most reliable forage. Most begin growth soon after the start of summer rains, and grow rapidly as long as effective rains continue. Growth rarely starts before July 1 and usually stops before September 30. In favorable years, some grasses also produce a little growth intermittently from February through June. However, more than 90 percent of perennial-grass growth is produced after summer rains begin. Height growth of flower stalks of Rothrock grama, slender grama, and Arizona cottontop illustrate the rapid growth during the brief summer growing period (fig. 8). Perennial grass production increases with increasing elevation and rainfall, as would be expected (fig. 9).

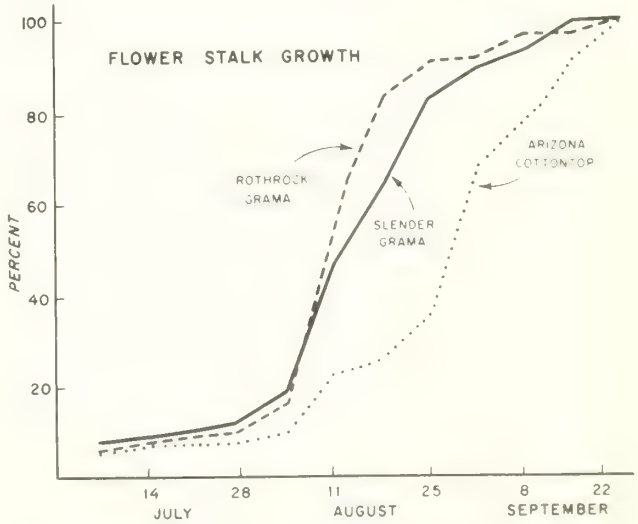


Figure 8.--Height growth of flower stalks of slender grama, Rothrock grama, and Arizona cottontop during 1 summer on the Santa Rita Experimental Range.

Figure 9.--Perennial grass production is greater at the higher elevations:

On brushy, low-rainfall, low-elevation parts of the range, perennial grass yields less than 20 pounds of herbage per acre.

At the higher elevation where the rainfall is greater and the brush has been removed, perennial grasses produce almost 450 pounds of herbage per acre.

Annual grasses produce 80 percent of the grass herbage on brushy, low-rainfall ranges

Grass production fluctuates extremely from year to year on brushy, low-rainfall range (fig. 10). Here, perennial grass yields may average less than 20 pounds per acre. Still, the perennial grasses are more stable than the annuals, which may produce several hundred pounds of herbage in a wet year and nothing at all in a year of drought (fig. 11).

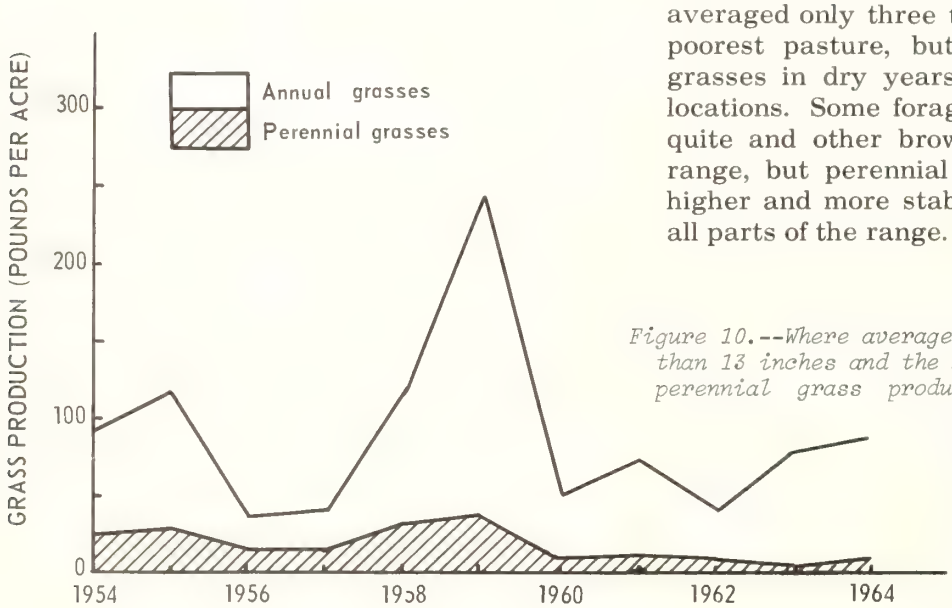


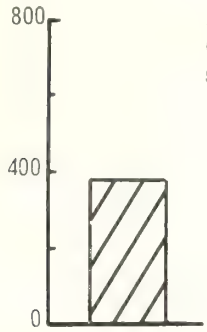
Figure 10.--Where average annual rainfall is less than 13 inches and the mesquite cover is heavy, perennial grass production averages only 17 pounds per acre. Total grass production varies greatly from year to year due mainly to changes in the yield of annual grasses. Average total grass production is 89 pounds per acre.

Perennial grasses produce 70 percent of the grass herbage on mesquite-free ranges where annual rainfall is 16 inches

Year-to-year fluctuations in forage production are marked at the upper elevations, but substantial amounts of forage are produced even in the poorest years (fig. 12). Average annual perennial grass production on the most productive pasture on the Santa Rita was 443 pounds per acre for the 1954—1964 period (fig. 13), 26 times the average yield for the least productive pasture a few miles away. Yields of annual grasses on the best pasture averaged only three times as great as on the poorest pasture, but production of annual grasses in dry years was negligible at both locations. Some forage is obtained from mesquite and other browse plants on the poor range, but perennial grasses are the key to higher and more stable forage production on all parts of the range.

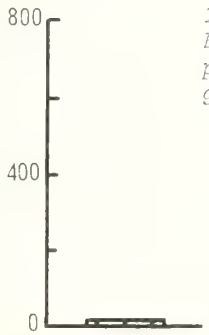
Figure 11.--Grass yield and general appearance in September. Year-to-year changes in herbage production are dramatic.

LOW-ELEVATION, LOW-RAINFALL RANGES

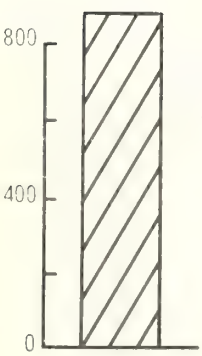


1 9 5 9 -- Good summer growing season

GRASS PRODUCTION (POUNDS PER ACRE)



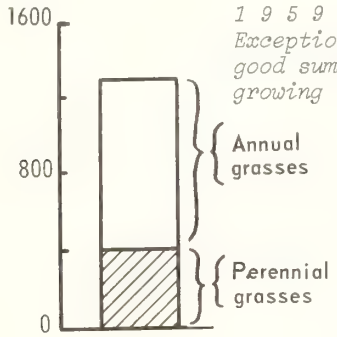
1 9 6 2 -- Exceptionally poor summer growing season



1 9 6 3 -- Exceptionally good summer growing season

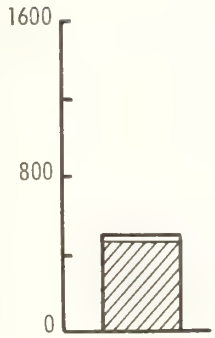
Figure 12.--Grass yield and general appearance in September. Fluctuations in yield are much less for perennial than for annual grasses.

HIGH-ELEVATION, HIGH-RAINFALL RANGES

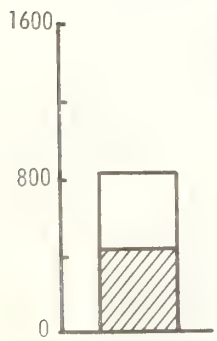


1 9 5 9 -- Exceptionally good summer growing season

GRASS PRODUCTION (POUNDS PER ACRE)



1 9 6 2 -- Poor summer growing season



1 9 6 3 -- Good summer growing season

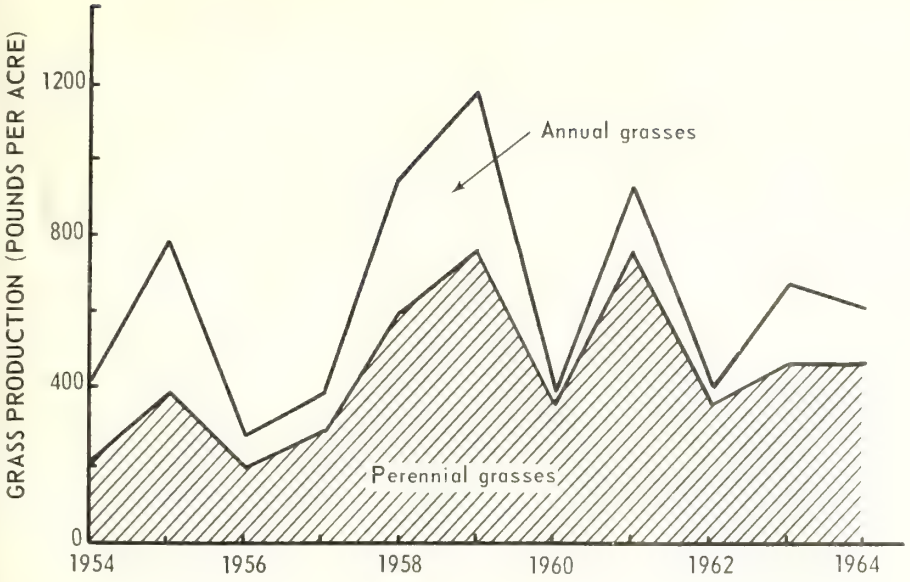


Figure 15.--Where annual rainfall averages 16 inches or more and the vegetation has been killed, average yields of perennial grass and total grass are 443 and 633 pounds per acre, respectively. In years of low rainfall and low total grass production (1956, 1957, 1960, and 1962) the annual grasses produce very little.

Grazing capacities of semidesert range vary from 5 to 25 head per section

The number of cattle that can be supported on semidesert grass-shrub range depends on the basic potential of that range and its condition. In the Southwest in general, rainfall increases with elevation, so the higher elevations have a higher potential for forage production. On the Santa Rita, ranges below 3,300 feet receive an average of 12 inches annual rainfall or less. Those above 4,000 feet usually receive 16 inches or more. Approximate grazing capacities of the upper, middle, and lower elevation ranges are listed in Table 1.

Table 1.--Estimated average yearlong stocking rates, by elevation and condition class, Santa Rita Experimental Range

Elevation (Feet)	Range condition		
	Good to excellent	Fair to good	Very poor
	Animal units per square mile		
Upper (Above 4,000)	20-25	15-20	< 15
Middle (3,300-4,000)	15-20	10-15	< 10
Lower (Below 3,300)	8-10	6- 8	< 6

GRAZING MANAGEMENT

Perhaps the most persistent factor that contributes to the improvement or decline of semidesert ranges is the grazing use. The season of grazing, the number of animals, and, to some extent, the intensity and distribution of grazing use can be controlled. Without such control, cattle graze forage from the best forage plants on the most accessible parts of the range 365 days per year. The natural end result of this process is that the most productive parts of the range eventually become the least productive. By forcing cattle to graze less on favorite parts of the range and more in areas where they ordinarily would not go, a higher percentage of the total forage crop can be harvested without damage to the most accessible areas. Improved grazing management probably is the most effective and economical tool for improving the productivity of semidesert cattle ranges.

Moderate grazing maintains range productivity

Grazing too closely or too frequently weakens perennial grass plants and cuts down seed production. Approximate standards of proper use developed for several important perennial grasses on the Santa Rita are as follows:

	Herbage removal (Percent by weight)
Arizona cottontop	40
Bush muhly	35
Curlymesquite	40
Dropseed	35
Grama:	
Black	45
Hairy	45
Rothrock	55
Side-oats	45
Slender	50
Sprucetop	40
Tanglehead	40
Three-awn	50
Wolftail	40

Cattle select the more nutritious forage

The quality of range forage, as measured by crude protein content, is highest during the summer growing season and lowest during the May-June drought. The protein content of hand-picked grass samples usually is less than 6 percent, except during the summer growing season. Even so, cattle selected plants and plant parts in such a way that the crude protein content of their diet was 9 percent or higher, an amount considered adequate for range cattle, in all months but January, May, and June (fig. 14).

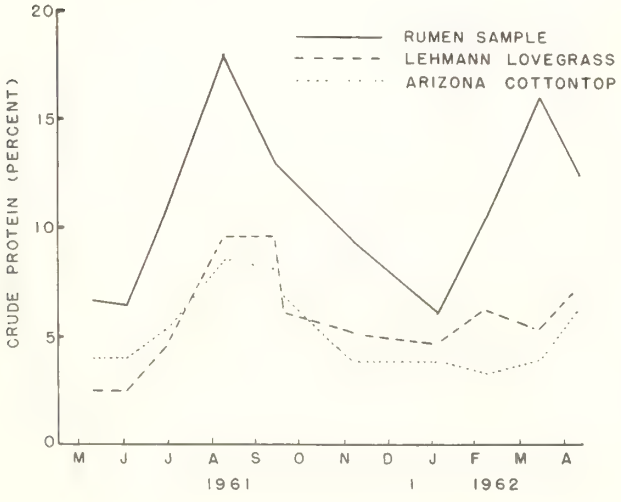


Figure 14.-- *Crude protein content of Arizona cottontop, Lehmann lovegrass, and of herbage samples taken from steer rumens at intervals of about 1 month from May 1961 to April 1962.*

About half of the grass plants should be ungrazed at the end of the grazing year

Tests show that the percentage of plants that remain ungrazed at the end of June can be used to estimate the degree of utilization (fig. 15). The stocking rate is about right if

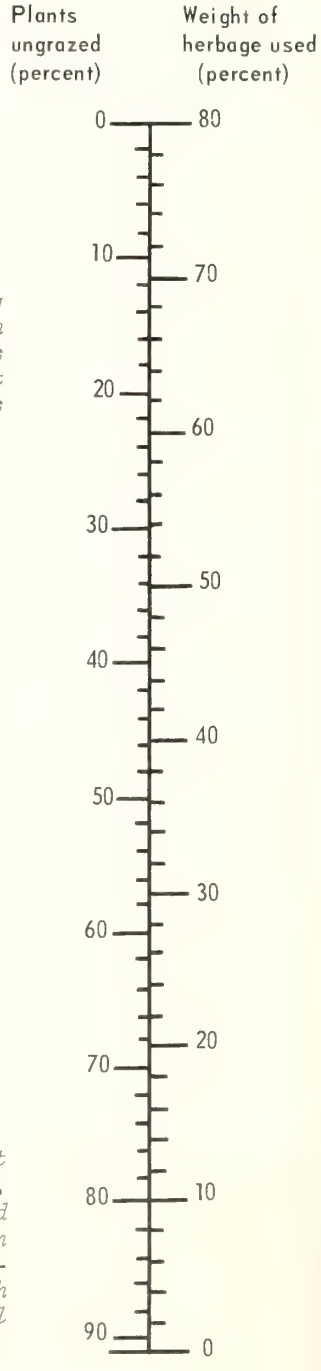


Figure 15.-- *Line scale showing relationship between percent of plants ungrazed and percent of perennial grass herbage consumed.*

40 percent of the herbage produced by perennial grasses is used each year. This level of use has been achieved if 46 percent of the perennial grass plants remain ungrazed when effective summer rains introduce the new forage year. This level of use also leaves an appreciable quantity of herbage on the ground (fig. 16).

Moderate to heavy yearlong grazing reduces number of seedlings of taller grasses

Seedlings or sets of 11 perennial grass species studied for 17 years became established every year. Species were black, hairy, side-oats, Rothrock, sprucetop, and slender gramas, Arizona cottontop, mesa three-awn, tanglehead, wolftail, and curlymesquite. More seedlings of tanglehead, black grama, and side-oats grama were established in exclosures than on grazed areas, but the grazed areas produced more seedlings of wolftail, Arizona cottontop, Rothrock grama, curlymesquite, sprucetop grama, and slender grama (fig. 17). The number of seedlings per year on meter-square plots ranged from 0.5 for Arizona cottontop on ungrazed areas to 29 for Rothrock grama on grazed plots.

Yearlong grazing shortens life of mid-grasses, lengthens life of grasses with dense basal foliage

Black grama, mesa three-awn, Arizona cottontop, and sprucetop grama are long-lived grasses, with some plants living 10 years or more (fig. 18). Rothrock grama, with maximum age of 5 years and average age of 1.3 years, is the shortest lived perennial on the Santa Rita. Except for Arizona cottontop, the species that lived longer on grazed plots were short grasses with mostly basal foliage. On the other hand, the plants that lived longer under protection were mainly mid-grasses. These differences in response to grazing help explain why the percentage of mid-grasses increases in response to moderate to light grazing, and decreases under heavy grazing.

Moderate stocking and alternate-year summer deferment improve rundown ranges

In 1954, the mesquite was killed on two pastures and was left undisturbed on two others. Since 1957, each pasture has been deferred during the summer growing season every other year and utilization of perennial grasses has averaged around 40 percent when measured in June. Grazing capacities have increased on both pairs of pastures (fig. 19). The estimated number of animal units required to graze 40 percent of the perennial grass crop increased by 169 percent between 1954 and 1961 on the mesquite-free pastures, an average of 2.5 head per section per year. Where the mesquite was alive, grazing capacity increased 62 percent, an average of 1.1 head per section per year during the same period.

Figure 16.--Key areas of this range near the end of June varied with the level of use:

In 1960, use was moderate (38 percent)

In 1964, use was heavy (58 percent)

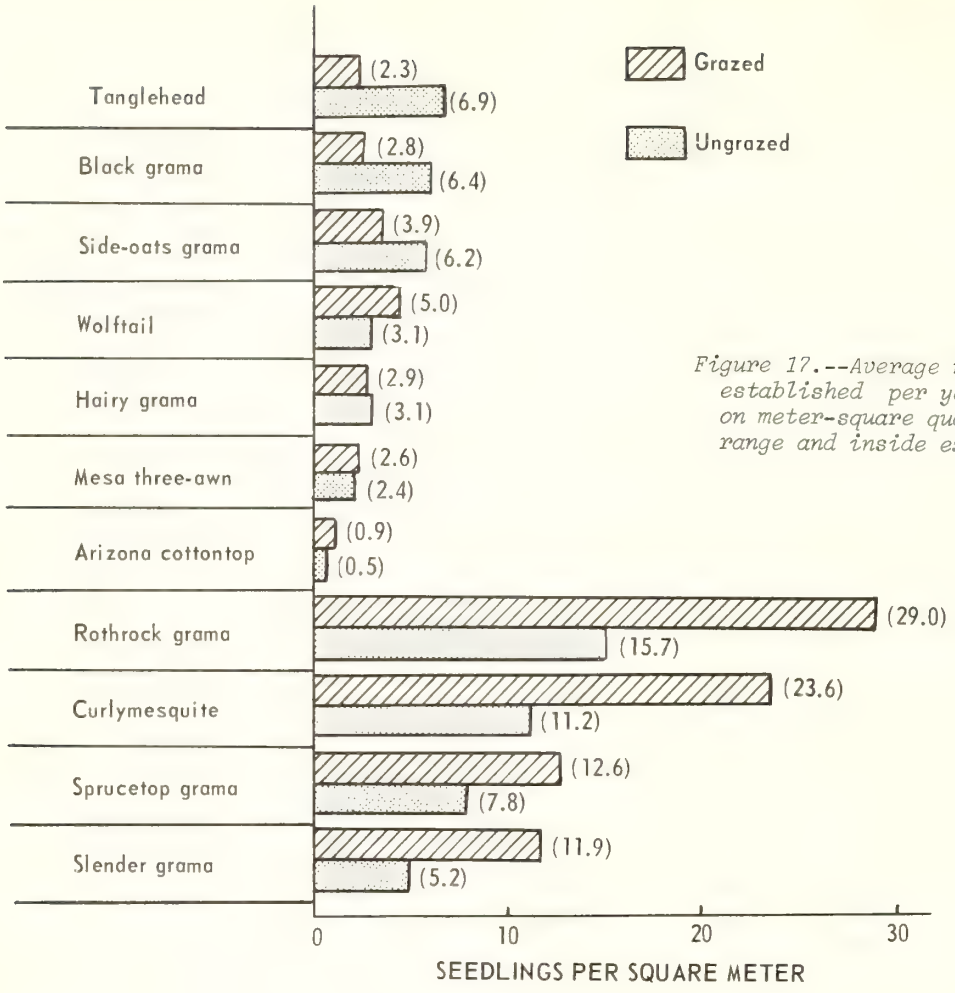


Figure 17.--Average number of grass seedlings established per year over a 17-year period on meter-square quadrats on yearlong cattle range and inside exclosures.

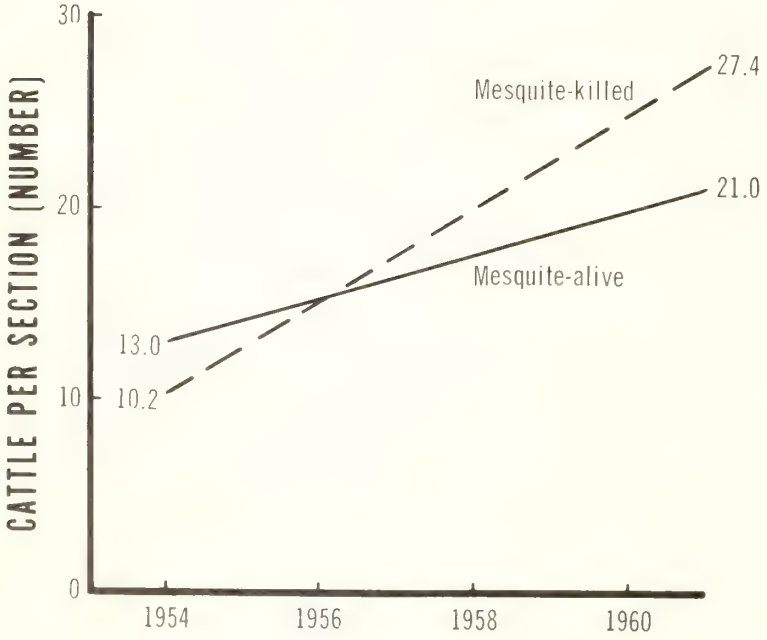


Figure 19.--Changes in number of animal units required to graze 40 percent of the perennial grass crop.

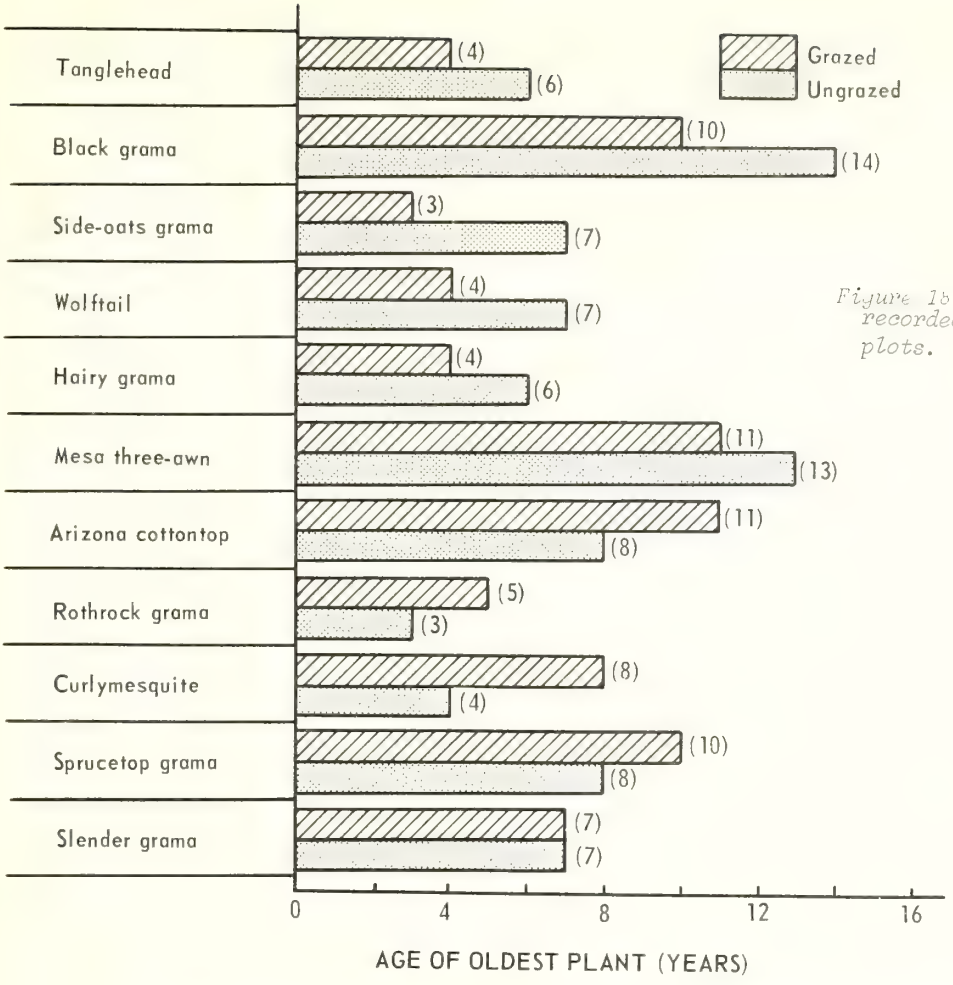


Figure 15.--Age of oldest plants recorded on grazed and ungrazed plots.

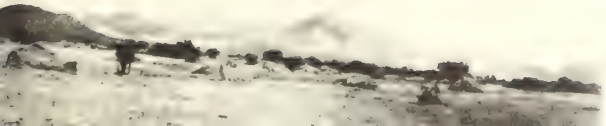
MESQUITE GROWTH

Mesquite now covers almost twice as much southwestern rangeland as it did in 1900. Where mesquite has taken over, forage production has declined (fig. 20). Mesquite produces some forage, but mesquite leaves and beans will feed fewer cattle than would the grass it crowds out. When mesquite completely replaces perennial grasses, forage production is reduced to less than one-third of capacity (fig. 21).

Figure 20.--Changes that accompany mesquite invasion.

In 1903, this relatively brushfree area had enough perennial grass to cut for hay.

In 1964, the same spot supported only scattered tufts of perennial grasses, with most of these protected by crowns of mesquite, burroweed, or cactus.



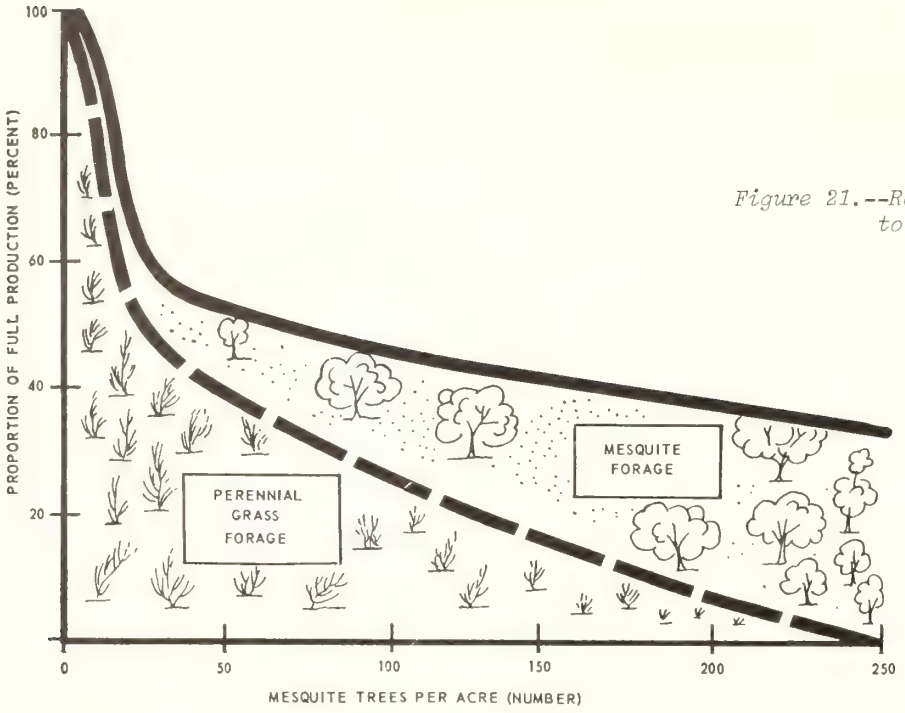


Figure 21.--Relation of mesquite abundance to forage production.

Vigorous grass stands retard spread of mesquite

Dense, vigorous stands of deep-rooted perennial grasses can almost prevent the spread of mesquite. Grasses reduce the number of seedlings that are established during the summer, and eliminate additional plants during the period October through July of the first year (figs. 22 and 23). In small plot tests, Arizona cottontop, black grama, and bush muhly inhibited the establishment of mesquite seedlings, bush muhly most effectively. Grasses retarded the development of lateral roots on the mesquite seedlings. Early mortality was attributed to shading as well as to competition for moisture.

Cattle spread mesquite seeds

It is well known that mesquite seeds are distributed in the droppings of livestock and other animals (fig. 24). A single cow chip may contain 1,500 or more mesquite seeds, of which ½ to ¾ are viable. Obviously the rancher who is trying to clear mesquite from his range should avoid bringing such quantities of new mesquite seed to cleared range. It takes about 8 days to clear mesquite seeds from the digestive tract of cattle. This means that cattle should be kept on a mesquite-free ration for a week before they are put on cleared range.

Some mesquite seeds live at least 10 years in the soil

Just how long mesquite seed will remain alive in the soil is uncertain, but 60 percent of a 50-year-old lot of seeds from a herbarium sheet at Tucson germinated. Seeds buried in the soil for 2, 5, and 10 years showed rapid declines in the percentage of sound seeds recovered, but the viability of the apparently sound seed did not decrease greatly with time (fig. 25). A recently germinated seed dug up at the end of 10 years was evidence that mesquite seed could remain in the soil for many years and still germinate naturally. Thus, any mesquite control program must reckon not only with existing mesquite plants and seed carried from other areas, but also with dormant seed in the soil.

Favorable growing conditions do not always increase height growth of mesquite in first year

A comparison of field-and nursery-grown mesquite seedlings showed that the more favorable conditions of the nursery were ex-

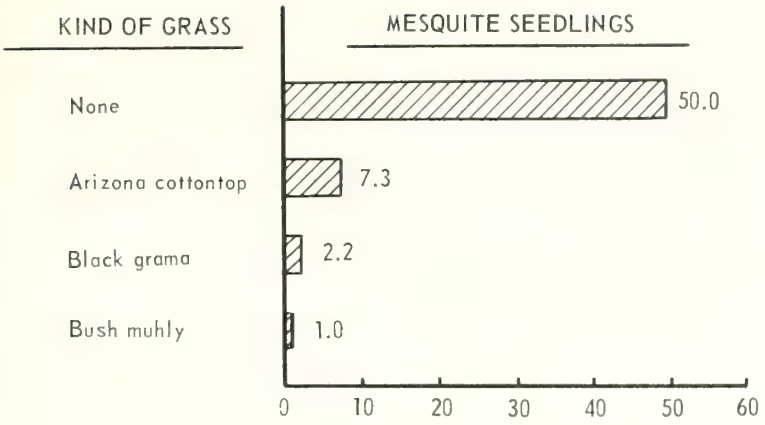


Figure 22.--Number of live mesquite seedlings in October per 100 seeds planted in July.

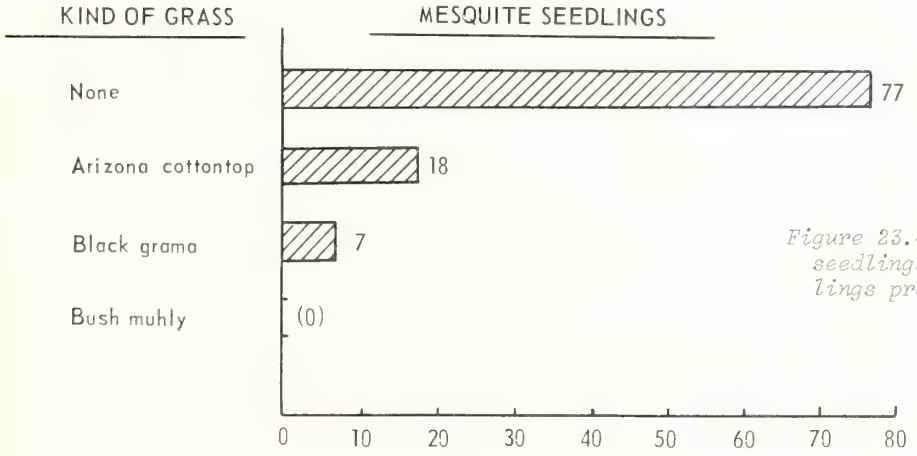


Figure 23.--Number of live mesquite seedlings on July 1 per 100 seedlings present the preceding October.

Figure 24.--Mesquite seeds are distributed in the droppings of livestock and other animals.

Cattle have a marked preference for mature and nearly mature velvet mesquite pods, and graze them avidly even in the presence of grass.

In a dense mesquite forest where little other forage was available, partially disintegrated cow chips were composed mainly of undigested pod segments and contained up to 1,670 seeds per chip.

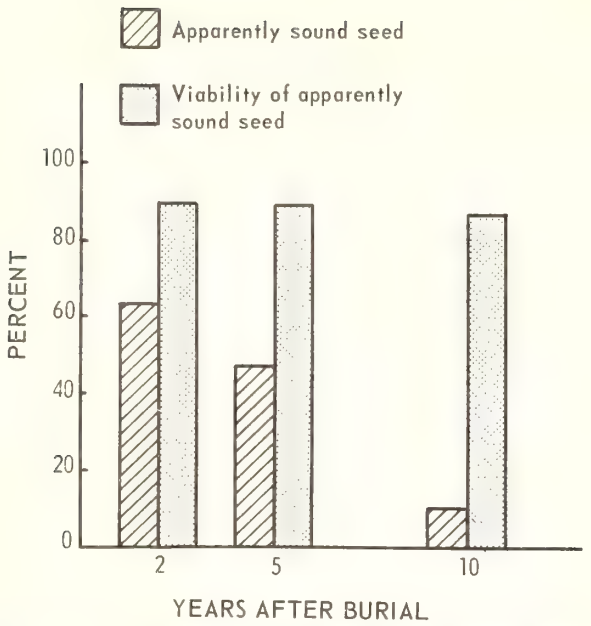


Figure 25.--Percent of mesquite seeds still apparently sound 2, 5, and 10 years after burial, and viability of apparently sound seed.

pressed in additional height growth of mesquite seedlings beginning in the second growing season. Slow height growth during the first growing season, even with adequate moisture, accounts in part for the susceptibility of mesquite seedlings to competition from perennial grasses. Because of frequent dieback and browsing, mesquite seedlings on the range may gain little height for many years (fig. 26).

Figure 26.--This mesquite seedling, established in 1949, was only 9 inches tall when photographed in December 1964.

MESQUITE CONTROL

Costs depend on size of trees and job

The most efficient method for controlling mesquite depends on a number of considerations. The number of trees per acre, their size and growth form, and the number of acres to be treated are all important (fig. 27). Costs vary greatly from job to job for many reasons. Approximate average costs for several methods are listed below:

Treatment	Equipment and labor	Chemical and materials	Total
	Costs per tree		
Grubbing	$ 0.015	____	$ 0.015
Diesel oil	.035	$ 0.015	.05
	Costs per acre		
Cabling and chaining	4.00	____	4.00
Foliage spraying (two treatments)	3.00	2.00	5.00

Small mesquites are easily grubbed

Plants 1 inch in diameter or smaller at the root crown can be easily killed by hand grubbing at any season of the year. Plants cut off 1 or 2 inches below the root crown do not sprout. Fewer plants will be overlooked if the range is traversed in marked strips and if grubbing is done in May and June when the new mesquite leaves contrast sharply with the dry grass. Grubbing is especially adapted for dense clusters of small mesquites around water, and for widely scattered seedlings on otherwise mesquite-free range. The cost of hand grubbing depends on the density of the mesquite, the wage rate and efficiency of the labor, and the relative stoniness of the soil.

Large machinery works best on large mesquite

Large bulldozers, with or without "stinger" attachments, are well adapted for uprooting scattered stands of relatively large trees.

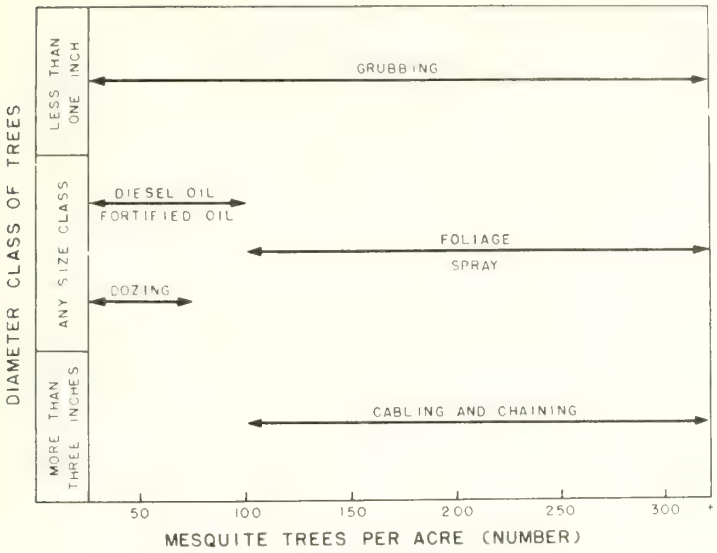


Figure 27.--The most efficient method for controlling mesquite depends on the size and number of plants per acre.

Dense stands of relatively large trees can be effectively opened up by chaining or cabling. However, chaining and cabling usually result in dense stands of mesquite sprouts from small mesquites that are broken off or roughed up but not uprooted by the chain or cable.

Large bulldozers are not recommended for small mesquite because too many are missed. Cabling and chaining usually require followup to kill sprouts from small plants that are not killed.

Large tractor-drawn root plows have not been used enough to determine their best place in mesquite control. More data are needed on costs, degree of mesquite control, and on the short- and long-time effects of root plowing on important forage grasses.

The cost of mechanical mesquite control varies so much due to so many factors that each job requires independent negotiations between the rancher and the contractor.

Diesel oil applied to stem bases is effective on trees of all sizes

Low-grade diesel oil or kerosene will kill mesquite at any time of year. Oil should be sprayed against the bark just above the ground line (fig. 28). Enough oil should be used to saturate the bark and flow down into the soil

Figure 28.--Treatment of mesquite with diesel oil:

Dormant buds are numerous in the root-stem transition zone. Oil is applied to kill these buds and to chemically girdle the tree.

A 2- to 4-gallon compressed-air sprayer equipped with a 3-foot piece of 1/4-inch copper tubing is a good device for applying the oil.

on all sides of the stem and in the crotches of low-branching trees. Trees with two or three stems up to 3 inches in diameter require about a pint of oil per tree. Diesel oil works well on mesquite that has a single stem or from two to four branches arising at or above the soil line. Results are best on sites where there has been no deposition of soil around the stem base.

Diesel oil is not recommended for flood-plain sites where the sprout buds are deeply buried by silt, or for the multiple-stemmed, low-growing form of mesquite that has no definite trunk.

The cost per tree of killing mesquite with diesel oil depends on the cost of the oil, the wage rate and efficiency of the labor, and the size and density of the mesquite. In mesquite stands of about 100 plants per acre, where plants range in size from seedlings to stems 5 inches in diameter, a good worker should treat 40 trees per hour, and a gallon of oil will treat 6 to 8 trees.

Airplane spraying with 2,4,5-T controls dense, extensive mesquite stands economically

Under ideal conditions, airplane spraying with 2,4,5—T (2,4,5—trichlorophenoxyacetic acid) in an oil-water emulsion top-kills more than 90 percent of the mesquite, and kills up to 50 percent of the plants outright (fig. 29). The most effective formulation is 1/3 to 1/2 pound acid equivalent per acre of a low-volatile ester of 2,4,5-T in 1/2 gallon of diesel oil and enough water to make 4 gallons of spray mixture. Continuous agitation of the mixture is essential. Two applications are necessary, 1 or 2 years apart.

The proper time for spraying is between April 15 and July 15. Mesquite should be sprayed when the new leaves are full-size, twig elongation has stopped, and developing pods are about one-half inch long. It is better to be a few days late than a few days early.

For jobs of 100 acres or more, the cost for herbicide and flying for two sprayings would range from $3.00 to $5.00 per acre at rates charged commercially in 1964.

Burning to kill mesquite most effective on small plants in June

Broadcast burning experiments in February, June, and November resulted in kills of 4, 29, and 10 percent respectively for mesquite of all size classes. The June burn was most effective for all sizes of mesquite, and mortality was much higher on small plants than larger ones (fig. 30). The percent kill on plants less than 0.5 inch in diameter was almost twice as great as for plants with stems between 0.5 and 1.0 inch, and three times as great as for plants 1.0 to 2.0 inches in diameter. These results suggest that burning to control mesquite should be done in June, and that results are best when the plants are small.

Figure 29.--Low-yielding, mesquite-covered range can be improved.

Unimproved range.

Range improved by spraying with 2,4,5-T to control mesquite, then seeding to Lehmann lovegrass.

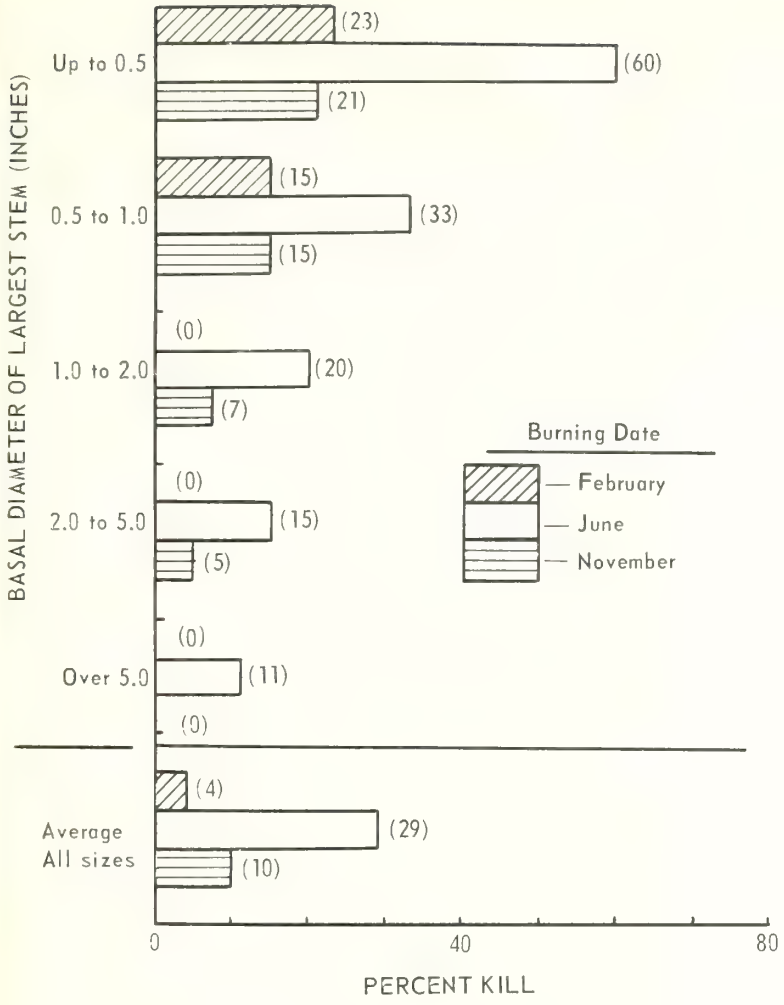


Figure 30.--Mortality of mesquite by size classes after burning in February, June, and November.

Perennial grasses recover quickly from a June burn if grazing is deferred during the summer rainy season immediately after the burn, and if the amount and distribution of rainfall are favorable. If summer drought or heavy grazing follow burning, the mortality of perennial grasses may be severe.

Mesquite control increases benefits of reseeding

Range that was seeded to Lehmann lovegrass by airplane in 1954 improved more rapidly where the mesquite was controlled by aerial applications of 2,4,5-T in 1954 and 1955 than where the mesquite was not controlled. Spraying killed about 90 percent of the top wood and over half of the plants. The cost of seeding was $3.00 per acre; the cost of seeding and mesquite control combined was $9.50 per acre. The sprayed range showed the greatest advantage in grass production during the second, third, and fourth seasons after spraying (fig. 31a). Cumulative net returns on the sprayed range returned more than the cost of spraying and seeding within 3 years (fig. 31b). Cumulative net returns on unsprayed range did not exceed the cost of seeding until the fourth year. These results show that rundown mesquite-grass ranges can be improved by seeding and management alone, but that the rate of recovery can be greatly increased by controlling the mesquite.

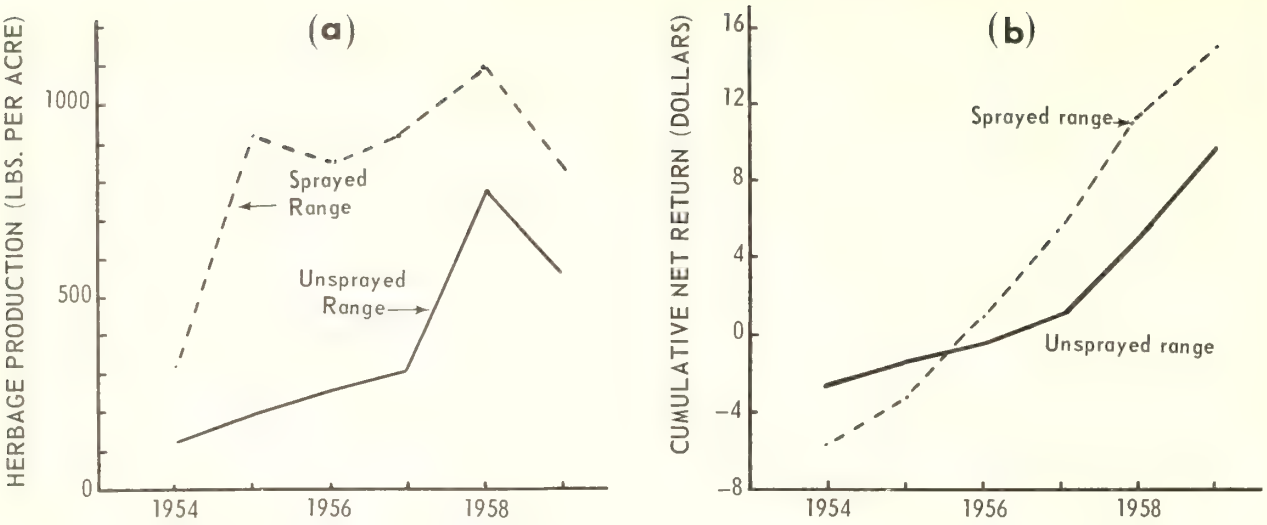


Figure 31.--One range was sprayed with 2,4,5-T in 1954 and 1955 to control mesquite; an adjacent range was not sprayed. In 1954, both ranges were seeded by airplane to Lehmann lovegrass.

Figure 32.--Changes in jumping cholla cactus: A, 1905; B, 1941; C, 1962.

JUMPING CHOLLA AS A RANGE PROBLEM

Jumping cholla is a nuisance on the range. It may not seriously reduce grass production, but it does interfere with the handling and movement of livestock. Cattle do eat some cholla fruits when green forage is scarce, but it is doubtful whether the food value obtained offsets the discomfort and injury involved.

New cholla plants rarely become established from seed, but dense stands of new plants are frequently established from scattered joints. Jumping cholla is not a fixed or ever-increasing component of the vegetation on any part of the Experimental Range. Instead, stands become established, develop rapidly for a few years, mature, and then decline (fig. 32). The decline may be dramatic, with 90 percent of the plants dying in 2 or 3 years.

Cholla can be killed with chemicals now on the market, but only if high rates of material are used. Completely wetting sprays of 2,4,5-T or TCA (trichloroacetic acid) will kill individual plants. Low-volume aerial applications, as applied to mesquite, are completely ineffective. Burning in June kills about one-third of the cactus, if there is enough fuel to carry a fire. Within a year or two after burning, however, large numbers of young cholla plants may become established from joints dropped off the partially burned parent plants. Mechanical measures such as chaining or cabling knock over and uproot most of the large cactus, but numerous new plants usually start from scattered joints. Studies to test the feasibility of controlling cholla by combinations of mechanical treatment and fire are in progress.

BURROWEED AS A RANGE PROBLEM

Invasions of grassland by burroweed have concerned cattlemen in southern Arizona since the turn of the century. Mature burroweed is a long-lived, woody half-shrub with a strong taproot. Occasional severe livestock losses from burroweed poisoning have been reported, but most of these have involved either a shortage of forage or cattle that were not familiar with burroweed. No cattle losses from burroweed poisoning have been recorded on the Experimental Range, where moderate to heavy stands of burroweed have persisted for many years. Cattle that grow up with burroweed apparently learn to leave it alone.

Invasion varies with cool-season precipitation

Burroweed does not invade grassland at a steady rate. Large numbers become established only in years of high winter and spring precipitation. Burroweed stands fluctuate greatly and sometimes quite rapidly (fig. 33).

Figure 33.--Burroweed stands become established in years with favorable winter-spring moisture, then decline from natural mortality until conditions permit the establishment of a new crop of seedlings: A, 1920, before burroweed invasion; B, 1935, dense mature burroweed stand; C, 1958, the old stand is about gone, but new seedlings are evident; D, 1962, the new crop of burroweed is approaching maturity.

Burning is more effective than chemical control

No satisfactory chemical method of control is available for burroweed. In years when there is an adequate supply of grass herbage, however, 90 to 100 percent of the burroweed may be killed by broadcast burning in June. Most of the burroweed that survives such fires is found in unburned or lightly burned islands. Burning is reasonably effective from mid-April to mid-September (fig. 34).

Burroweed control increases yields of annual grasses

Average yields of annual grasses during a 10-year period were higher on burroweed-free plots than where the burroweed was not removed. Burroweed control increased annual grass yields in the presence of mesquite as well as on plots where mesquite was killed (fig. 35). Yields of perennial grasses, on the other hand, were greater in the presence of burroweed. It is suspected that heavier grazing on the burroweed-free plots was responsible for the decrease in perennial grass production. Whatever the cause, the results of this study do not justify controlling burroweed to increase perennial grass yields.

RANGE RESEEDING

Range reseeding studies began on the Santa Rita soon after the Range was established in 1903. Studies to date have indicated that: (1) grasses should be seeded in May or June immediately before the start of the summer rainy season, (2) burroweed, mesquite, cactus, or other competing brush should be removed before seeding, and (3) the chances for success are improved by preparing a good seedbed.

The best sites for reseeding have productive, medium-textured soils, are above 3,500 feet elevation, and receive 14 inches or more rainfall annually. On these sites, Lehmann and Boer lovegrasses are the best species to use.

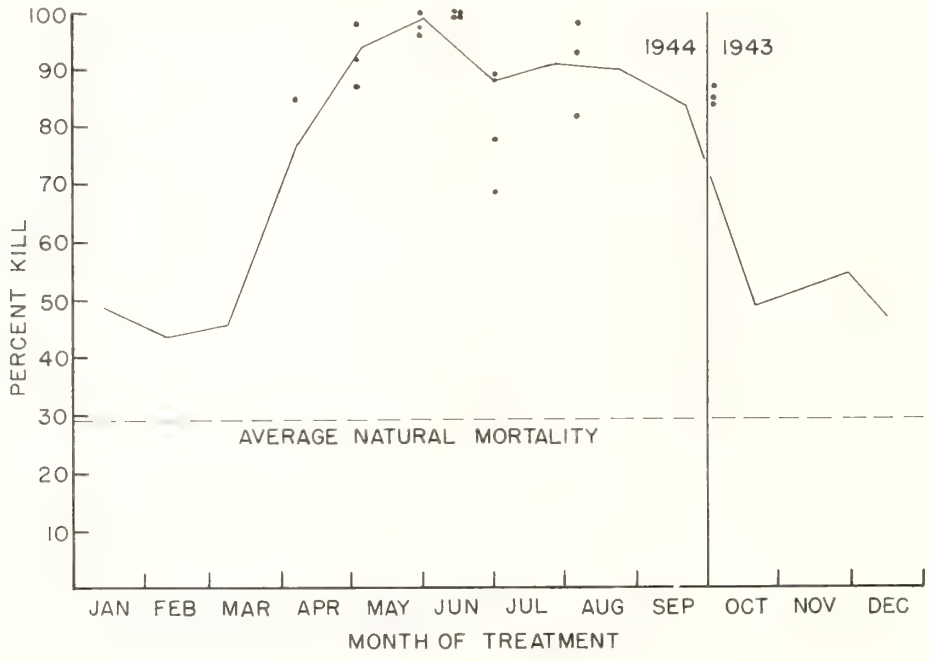


Figure 34.--Percentage of burroweed after burning at 4-week intervals from October 21, 1943, to September 21, 1944. Each point marked by a dot represents a burn on the date indicated but at a different location and usually in a different year.

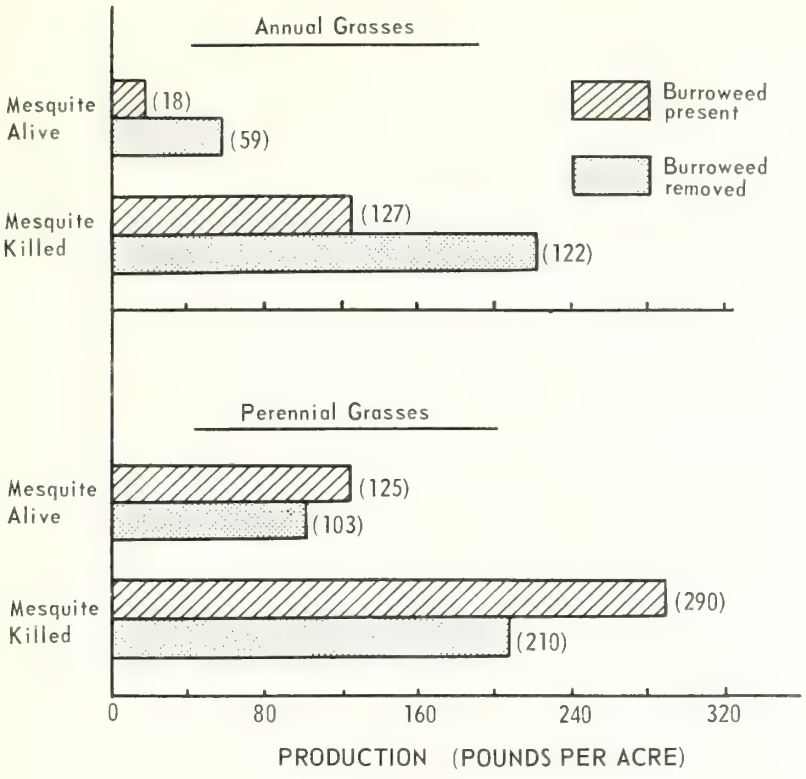


Figure 35.--Effects of burroweed control on yields of annual and perennial grasses on mesquite-infested and mesquite-free range.

Lehmann is easier to establish, but Boer is more palatable and longer lived. Arizona cottontop and black grama are more difficult to establish. Weeping lovegrass and side-oats grama are suitable for the more moist sites. Wilman lovegrass can be used where temperatures do not fall below 10° F.

On upland areas receiving less than 14 inches of rainfall, Lehmann lovegrass is the only species that can be generally recommended. Reliable species and methods have not been developed for reseeding ranges that receive less than 11 inches of precipitation yearly.

RODENTS AND RABBITS

Rodents and rabbits use vegetation that would otherwise be available for livestock, and thereby lower the overall grazing capacity of the range. In 1937, it was estimated that rodents and rabbits consumed about two-fifths of the total forage. Animal numbers for the Experimental Range, and their forage consumption, were as follows:

Species	Animals	Forage consumed per animal per year	Forage consumed per year
	(no.)	(lbs.)	(lbs/acre)
Allen jackrabbit	10,300	175.20	35
California jackrabbit	620	120.45	1
Arizona cottontail	3,530	54.75	4
Roundtail groundsquirrel	29,780	8.21	5
Bannertail kangaroo rat	87,125	5.53	9
Merriam kangaroo rat	42,025	2.41	2
Total	———	———	56

Rodents and rabbits can be more detrimental than cattle to range vegetation, because they graze much closer and may even dig up root systems during dry periods. Also, certain species, particularly kangaroo rats, help establish unwanted shrubs by storing seeds in small caches about 1 inch below the soil surface. Seeds not used by the rodent are planted at an ideal depth, and thus frequently give rise to new plants. Jackrabbits and some kangaroo rats are more abundant on ranges in poor condition, where their activities tend to perpetuate the undesirable condition of the range. A relatively small rodent population can consume the entire seed crop of forage grasses on low-rainfall range in poor condition.

EDUCATIONAL OPPORTUNITIES

The facilities of the Santa Rita Experimental Range are often used for training schools, for undergraduate field work, for field meetings of range management and conservation groups, and for training programs of the Foreign Agricultural Service.

Opportunities for graduate students to undertake fundamental research in the ecology and management of semidesert ranges are excellent.

Visitors are always welcome. To obtain more detailed published information about the experimental work, ask the resident technicians, or send a request to the Director, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

COMMON AND SCIENTIFIC NAMES USED

Acacia	*Acacia* spp.
Burroweed	*Aplopappus tenuisectus* (Greene) Blake
Cactus	*Opuntia*
Jumping cholla	*fulgida* Engelm.
Pricklypear	Principally *engelmannii* Salm-Dyck
Calliandra	*Calliandra* spp.
Cottontop	*Trichachne*
Arizona	*californica* (Benth.) Chase
Curlymesquite	*Hilaria belangeri* (Steud.) Nash
Dropseed	*Sporobolus* spp.
Grama	*Bouteloua*
Black	*eriopoda* Torr.
Hairy	*hirsuta* Lag.
Side-oats	*curtipendula* (Michx.) Torr.
Slender	*filiformis* (Fourn.) Griffiths
Sprucetop	*chondrosioides* (H.B.K.) Benth.
Rothrock	*rothrockii* Vasey
Lovegrass	*Eragrostis*
Boer	*chloromelas* Steud.
Lehmann	*lehmanniana* Nees
Weeping	*curvula* (Schrad.) Nees
Wilman	*superba* Peyr.
Mesquite	*Prosopis*
Velvet	*juliflora velutina* (Woot.) Sarg.
Mimosa	*Mimosa* spp.
Muhly	*Muhlenbergia*
Bush	*porteri* Scribn.
Tanglehead	*Heteropogon contortus* (L.) Beauv.
Three-awn	*Aristida*
Mesa	*hamulosa* Henr.
Santa Rita	*glabrata* (Vasey) Hitchc.
Wolftail	*Lycurus phleoides* H.B.K.

Martin, S. Clark.
1966. The Santa Rita Experimental Range. U. S. Forest Serv. Res. Paper RM-22, 24 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Research was begun in 1903 on the Santa Rita, south of Tucson, Arizona, to learn how to attain maximum sustained forage and beef production on semidesert range with reasonable costs. Results reported cover forage production, including dependence on perennial grasses, grazing management, and methods and advantages of controlling mesquite and other undesirable plants.

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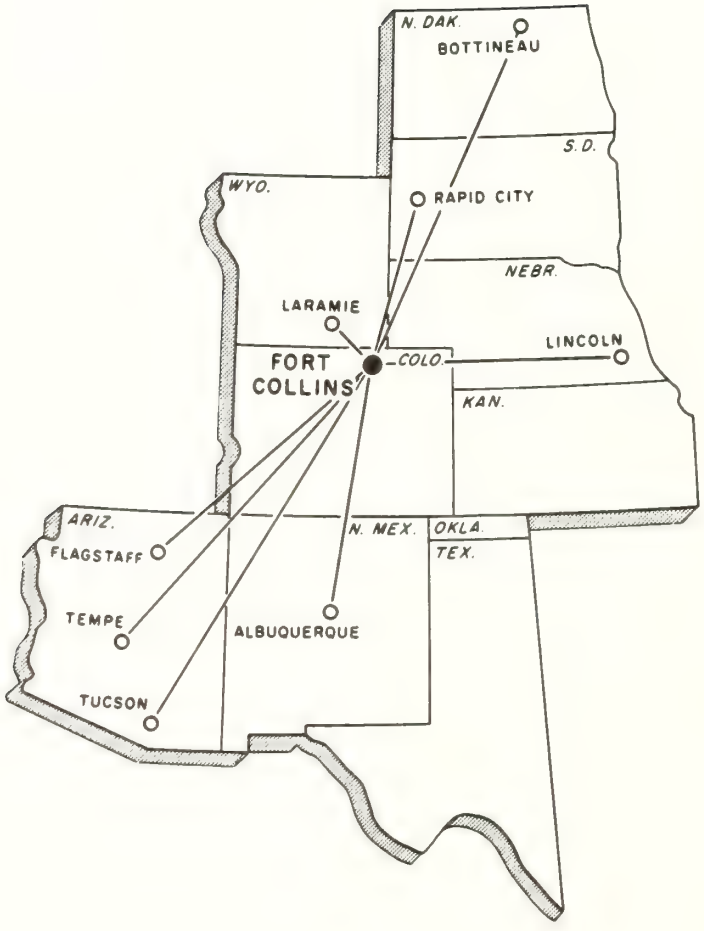
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Sediment Yields from High Mountain Watersheds, Central Colorado

by Charles F. Leaf

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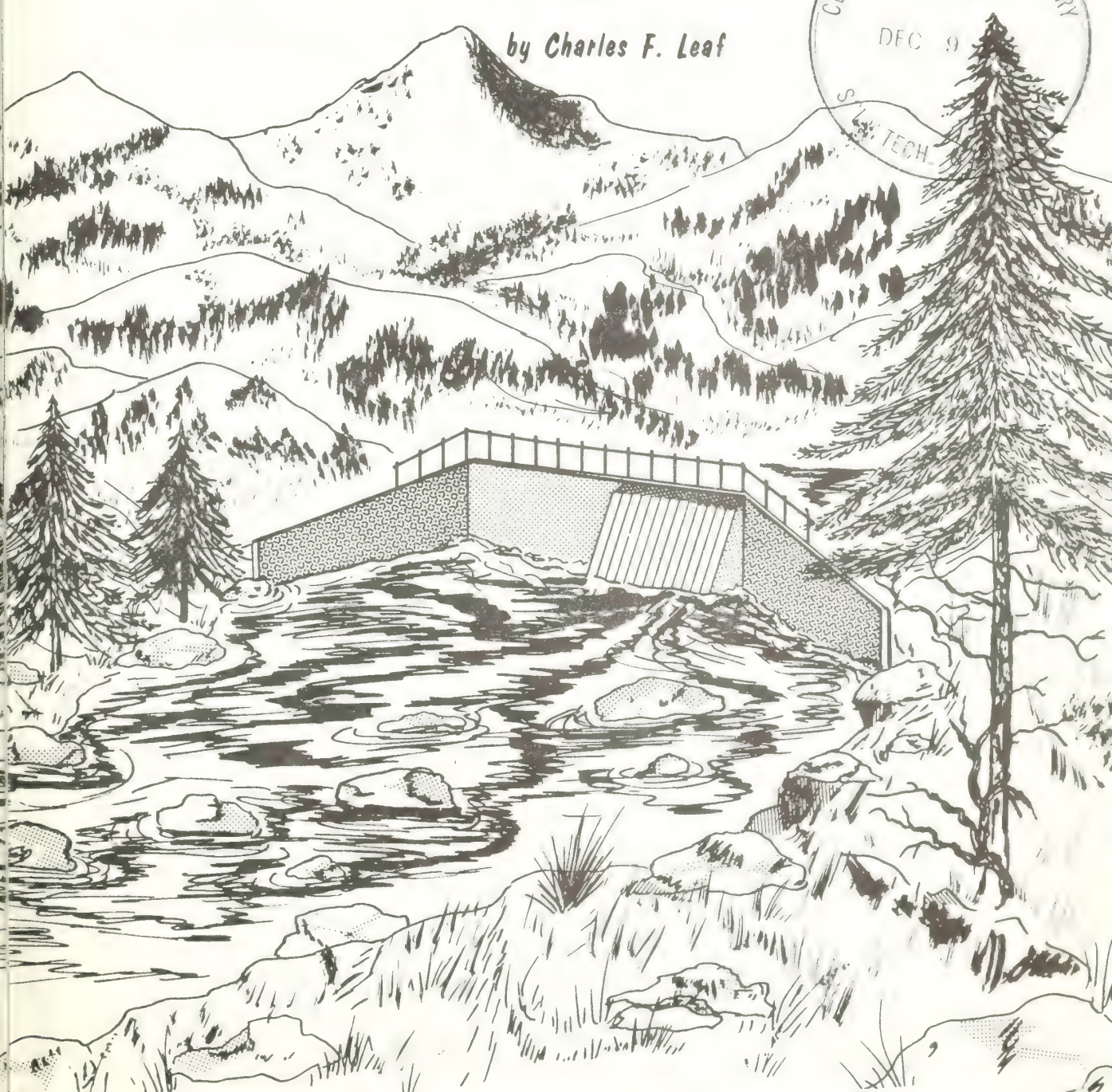

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SEDIMENT YIELDS FROM HIGH MOUNTAIN WATERSHEDS, CENTRAL COLORADO

by

Charles F. Leaf, Associate Hydraulic Engineer

Rocky Mountain Forest and Range Experiment Station[1]

[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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Sediment Yields from High Mountain Watersheds, Central Colorado

Charles F. Leaf

With increased development of our water resources, we can expect a greater need for evaluating sediment yields from small mountainous watersheds. At present, insufficient data are available to make adequate estimates, especially in the high runoff areas of the central Rocky Mountains. In general, sediment yields from these areas are not high, but it is reasonable to expect that they are of sufficient magnitude to influence the design and operation of water projects.

In addition to development of existing water resources, efforts are currently underway to increase water yields from stable high-mountain watersheds by forest management. These activities require that extensive road systems be constructed. Information is needed on the effects of roads and forest-cover changes on sediment yields.

This paper discusses sediment yields from two undisturbed watersheds and one watershed from which one-half of the merchantable timber was removed by careful timber harvesting. The necessary logging roads on the harvested watershed were planned and built to minimize erosion. Selected geomorphic characteristics of the watersheds are evaluated. Magnitude-frequency relationships are developed for estimating long-term sediment yields by the "design period" approach.

The Experimental Watersheds

Location

The three watersheds are part of the Fraser Experimental Forest, which lies 65 miles west of Denver, Colorado (fig. 1). They are tributary watersheds of St. Louis Creek, which in turn flows into the Fraser River. Dominant vegetation is lodgepole pine and spruce-fir forests typical of the central Rocky Mountains.

Their areas are:

	Acres
Fool Creek	714
Deadhorse Creek	667
Lexen Creek	306

Deadhorse and Lexen Creeks are paired watersheds (fig. 2) on the west side of the Experimental Forest. Fool Creek (fig. 3) is situated on the east side of the Forest.

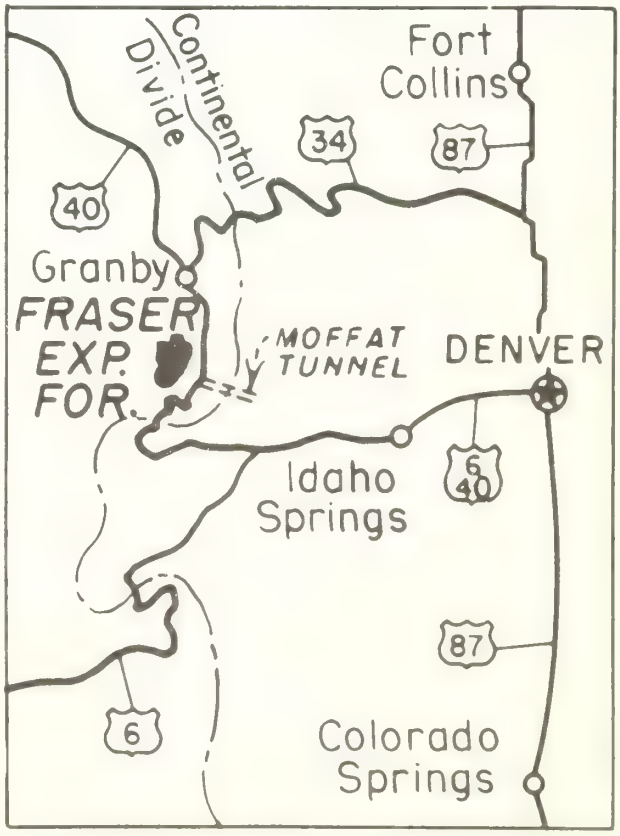


Figure 1.--Location map for Fraser Experimental Forest.

Figure 2.--Lexen (left) and Deadhorse (right) experimental watersheds, Fraser Experimental Forest.

To determine the result of careful timber harvesting and road building on streamflow, one-half of the merchantable timber was cut on the Fool Creek watershed. Streamflow has been measured since 1941. The logging road system, built between 1950 and 1952, consists of 3.3 miles of main access road located to avoid the main stream channel and to minimize soil disturbance. Timber was made accessible by an additional 8.8 miles of spur roads laid out approximately on the contour. These spur roads were provided with surface drainage and culverts at stream crossings. When logging was finished, the spur roads were seeded to grass and culverts removed on alternate roads to reduce traffic.

Timber was cut in alternate clearcut strips to favor reestablishment of trees on the cutover portions. Logs were skidded by horses to the contour spur roads, approximately 400 feet apart. Logging slash was lopped and scattered, and protected the soil surface. No trees were cut within 90 feet of the main stream channel to avoid risk of bank erosion and debris dams.

Timber harvest began in 1954 and was completed by fall of 1956. The area cutover was 243 acres. An additional 35 acres was cleared to build the road system. The total area from which trees were removed is 278 acres.

Climate and Water Yield

The climate is cool, with an average annual temperature of approximately 35° F. At 9,000 feet, the annual precipitation averages about 24 inches, of which two-thirds occurs as snowfall. Annual precipitation has varied from 15 to 30 inches. Water yield from the watersheds is 45 to 55 percent of the annual precipitation, and has varied from 1/2 to 1-1/2 acre-feet per acre. Generally, streamflow begins to increase from a winter minimum in April, and reaches peak levels in June. About 80 percent of the annual water yield takes place from April through October.

Geology, Landforms, and Soils

The three watersheds represent topographic characteristics typical of the Southern Rocky Mountain province. Fool Creek watershed is part of the remnants of an old peneplain, which is nearly level in extent but dissected along its sides by mountain glaciers. It is characterized by long, gentle, relatively uniform slopes. Deadhorse and Lexen watersheds have relatively narrow, steep-sided valleys filled with alluvium and glacial outwash.

Slope properties of the three watersheds are shown in figure 4. Lexen and Deadhorse

watersheds are both steeper than Fool Creek, with average slopes of approximately 36 and 39 percent, respectively. The average slope of Fool Creek is approximately 26 percent.

Soils are not easily eroded in the Fraser area. In general, the parent material of the soils on the watersheds was derived from gneiss and schist rocks (Retzer 1962).[2] Typical soils contain angular gravel and stone and very little silt and clay. The soils are very permeable, and are capable of storing considerable water during snowmelt. The mineral soil is normally covered with a dense litter composed of needles, rotting wood, and moss.

Near the top of Deadhorse and Lexen watersheds are soils which have developed in material weathered from sandstones. The soils are shallow over sandstone bedrock. They have a large amount of stone in their profile, and have fine sand or sand textures. The soils include a high percentage of rock outcrops.

[2]*Names and dates in parentheses refer to Literature Cited, p. 15.*

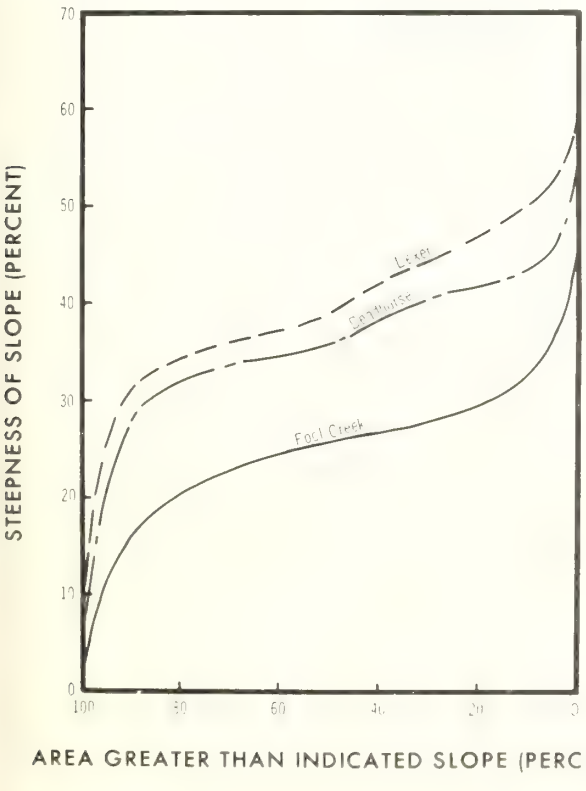


Figure 4.--Area-slope curves for Fool, Deadhorse, and Lexen watersheds.

Figure 3.--Timber cutting pattern and road system on Fool Creek experimental watershed. Annual sediment accumulation is measured in the debris basin at the lower right-hand corner of photograph.

Alluvial soils occur along the main streams of all three watersheds. The parent material is a mixture of glacial till, glacial outwash, and recent valley fill. Three to four inches of litter covers the soil. The water table is generally near the surface, but dry spots occur locally on the higher areas of the glacial till deposits. There is little or no surface erosion, although there is some minor cutting along streambanks. Included on each watershed are bogs that owe their origin to seeps and springs which emerge on the slopes. Soils in these bogs are highly organic. The surface material consists of a mixture of wood, roots,

willow leaves, needles, and decomposed remains of various grasses. Under this organic material are layers of silt and clay with a high proportion of gravel and stones. Because of the vegetation and litter produced, it appears that these bogs serve well to retard excessive runoff and decrease channel erosion.

Vegetation

Alpine vegetation, found at the top of all three watersheds, is composed primarily of grasses and sedges which form meadow and tundra types. Clumps of shrubby willows are interspersed, usually on moist sites. There are large areas of bare rock. Soil-covered dry and exposed slopes support only cushion plant stands.

Between alpine and true forest there is usually a transition zone of stunted trees. Below this is the true forest composed of Engelmann spruce, subalpine fir, and lodgepole pine. Pine is more abundant at lower elevations and on south-facing slopes. There are small, scattered patches of quaking aspen. The forest floor is covered with deep litter. The most abundant minor vegetation is grouse whortleberry. Young trees and buffaloberry form an understory. More complete accounts of the vegetation can be found in Retzer (1962).

Sediment Measurement, Characteristics, and Yields

Records of Annual Sediment Yields

The period of record from each watershed is as follows:

Fool Creek	1952-65
Deadhorse Creek	1955-65
Lexen Creek	1956-65

Sediment yields in cubic feet per square mile ($ft.^3/mi.^2$), and annual instantaneous peak discharges in cubic feet per second per square mile (c.s.m.), are summarized for each watershed (table 1). The sediment yields are

Table 1.--Annual sediment yield and peak discharge from Fool, Deadhorse, and Lexen watersheds for period of record, 1952-65

Year	Sediment yield			Annual peak streamflow		
	Fool Creek	Deadhorse	Lexen	Fool Creek	Deadhorse	Lexen
	--- Ft.^{3}/mi.^{2} ---			---- c.s.m. ----		
1952	1/ 1,408	--	--	21.7	--	--
1953	703	--	--	14.1	--	--
1954	(2/3/)	--	--	2.2	--	--
1955	(2/3/)	131	--	6.1	3.8	--
1956	3/ 1,150	544	226	17.1	9.8	13.0
1957	2,200	718	393	21.4	13.1	22.5
1958	1,344	266	468	16.1	11.4	18.0
1959	270	157	83	13.4	7.5	13.0
1960	436	157	80	14.7	8.2	11.9
1961	192	32	13	7.8	3.7	6.7
1962	512	403	197	12.5	9.2	12.3
1963	(2/)	29	8	4.6	2.4	2.2
1964	(2/)	47	67	8.8	5.1	7.1
1965	779	223	130	17.4	9.2	12.5

1/ Road construction on Fool Creek.
2/ Negligible accumulation.
3/ Timber harvest on Fool Creek.

Figure 5.--Fool Creek debris basin just downstream from San Dimas flume. The capacity of this pond is approximately one-fourth acre-foot.

based upon gross volumes of mineral and organic material as determined by annual surveys of debris basins. Survey points were located on 3- to 5-foot grids with elevations measured to the nearest 0.01 foot. The basins were drained before each survey was made. Typical debris basins are shown in figures 5 and 6.

Properties of Sediment Deposits

Except for flow conditions, the entrainment, transportation, and subsequent deposition of a sediment is largely dependent on the properties of the sediment itself. A useful and precise description of the more pertinent properties of a sediment can be obtained by means of a gradation or frequency distribution curve. Such a curve provides a means for grouping the sediment into different size classes and grades.

Figure 7 shows average grain-size distribution curves for accumulated sediment from the three debris basins. The grading curves were quantitatively evaluated by computing coefficients of uniformity (Cu) and curvature of gradation curves (Cc) according to Hazen's criteria (U.S. Bur. Reclam. 1960).

The measure of size range is called the coefficient of uniformity (Cu), which is the ratio of the 60-percent-finer-than size (D_{60}) to the 10-percent-finer-than size (D_{10}). The shape of the grain-size curve is given by the coefficient of curvature (Cc), which is the ratio of the square of the 30-percent-finer-than size $(D_{30})^2$ to the product of (D_{60}) and (D_{10}).

The coefficients were used to classify the samples according to the Unified Soil Classification System (U.S. Bur. Reclam. 1960), which provides for precise delineation of soil groups by laboratory analyses. There are three distinct sediment groups (fig. 7), including:

1. Well-graded gravel with little or no fines,
2. Poorly graded sand with little or no fines, and,
3. Silty or fine sand.

The samples of finer sand were taken from the Fool Creek debris basin; its presence in appreciable quantities is most likely the result of road construction on the watershed.

One of the main interests of those working with deposited sediments involves predicting the depletion of reservoir storage. Prior to construction of a reservoir, the sediment transported by a river or stream is usually measured on the basis of weight per unit time. To obtain an estimate of the expected

Figure 6.--Deadhorse weir. The rectangular debris basin behind the weir has a surface area of 408 square feet. A similar installation with a surface area of 200 square feet was constructed on Lexen watershed.

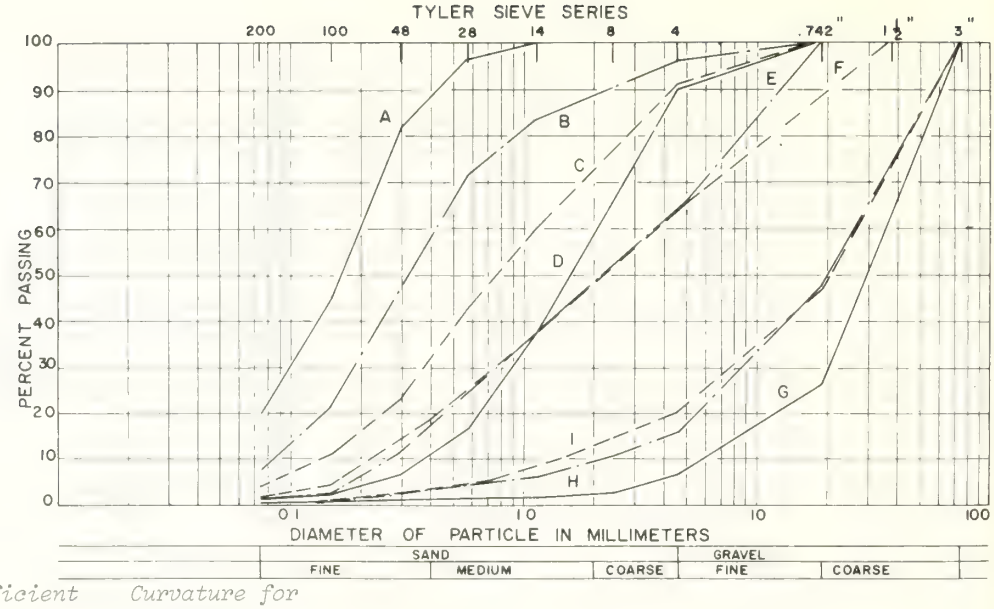


Figure 7.--Typical grading curves for deposited sediment from Fool, Deadhorse, and Lexen debris basins.

Curve	Watershed	Coefficient of uniformity (Cu)	Curvature for gradation curves (Cc)
A	Fool Creek	3.3	0.88
B	Deadhorse	4.8	.96
C	Lexen	7.7	.83
D	Fool Creek	5.5	1.07
E	Deadhorse	12.9	.54
F	Lexen	16.5	.70
G	Fool Creek	6.2	1.9
H	Deadhorse	11.2	1.3
I	Lexen	18.2	1.6

volume to be occupied by the deposited sediment, it is necessary to have its specific weight. Experience has shown that the specific weight of deposits varies with mechanical composition, environment, and time. The variation of specific weight (dry unit weight) with sediment class and particle size is summarized for Fool, Deadhorse, and Lexen debris basins (table 2). The deposits were laid down for a period of 2 years prior to sampling.

Trap Efficiency

Brune (1953) has pointed out that the trap efficiency of a reservoir or debris basin depends on a number of factors, such as ratio between the storage capacity and inflow, age of the reservoir, shape of the reservoir basin, type of outlets and method of operations, the size grading of the sediment, and behavior of the finer sediment fractions under various conditions. The trap efficiency of reservoirs is affected by the same factors, regardless of reservoir size.

Table 2.--Variation of specific weight with sediment class and particle size

Debris basin and class of sediment	Median diameter	Particles greater than 1 mm.	Specific weight
	mm.	Pct.	Lb./ft.^{3}
Fool Creek:			
Gravel	30.00	99.0	--
Sand	2.69	78.5	110.1
Sand	2.00	70.0	127.8
Sand	1.63	69.0	106.8
Sand	1.30	63.0	118.6
Sand	.29	3.0	78.8
Fine sand	.13	0	45.7
Fine sand	.12	0	60.6
Deadhorse Creek:			
Gravel	21.20	93.5	134.9
Fine gravel	4.60	76.5	111.3
Fine gravel	1.85	64.5	111.3
Sand	1.41	57.8	105.6
Sand	.35	20.0	79.0
Sand	.33	18.0	79.0
Lexen Creek:			
Gravel	20.70	93.4	131.5
Gravel	2.55	69.0	84.0
Gravel	2.25	66.0	84.0
Sand	.89	47.0	77.4
Sand	.72	41.2	77.4

Virtually all information available on trap efficiency has been based on data from larger storage reservoirs in lowland areas. Consequently, relatively little is known about the efficiencies of smaller water-retarding structures in mountainous regions.

Data presented by Moore et al. (1960) from the debris basin program in the Los Angeles area indicate that in nearly all cases, trap efficiencies approach 100 percent, for coarse-grained debris, even during periods when both inflow and outflow take place.

The debris from Fool, Deadhorse, and Lexen debris basins is likewise coarse (table 2); it is believed that the basins trap virtually all of the eroded material. Suspended sediment samples taken from the outflow of the debris basins during peak streamflow in 1964 and 1965 showed maximum concentrations of less than 5 p.p.m. Peak flows during the 1965 snowmelt season were the highest since 1957.

Sediment Yield in Relation to Peak Streamflow

The total amount of sediment yielded from a stream depends upon the physical characteristics of the watershed and climatic factors. Furthermore, it is generally assumed to be derived from two erosional processes--sheet erosion and channel erosion. The total sediment load for a stream, then, is recognized to be composed of fine material or wash load derived from sheet erosion, and bed-material load derived from channel erosion.

The quantity of wash load in a stream at any time depends on the rate at which fine particles become available from the watershed, and not on the ability of the flow to transport them. It is a function of such factors as intensity, quantity, and distribution of rainfall, soil type, vegetation cover, relief, and channel density.

Bed-material load in a stream is mainly derived from gully erosion, streambank erosion, and channel degradation. The quantity of bed-material load in a stream at any time depends on the hydraulic characteristics of the flow.

Where a major part of the total load is composed of material which moves as bedload, a good relationship is expected between sediment yield and discharge. Concentration of wash load, however, is more directly related to supply rather than discharge. Hence, the climatic and physical factors affecting its transport have a greater influence than does the discharge. Relationships between annual instantaneous peak discharge and annual accumulated debris for Fool, Deadhorse, and Lexen watersheds (fig. 8) show a good correlation between sediment yield and annual peak flow. All correlation coefficients tested were significant at the 95-percent level of confidence. The linear relationships (fig. 8) accounted for an average of 83 percent of the variance.

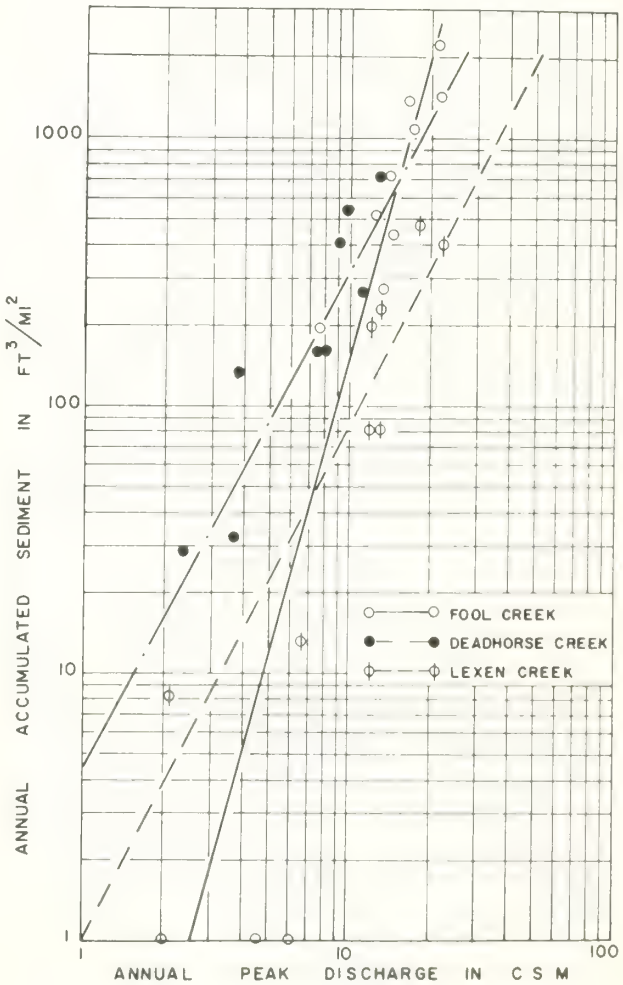


Figure 8.--Relationships between sediment yield and peak discharge for Fool, Deadhorse, and Lexen watersheds.

Sediment yields from these watersheds are also highly correlated with total annual flows. The relationships indicate that a major portion of the total sediment load is composed of bed material derived from streambank erosion and channel degradation. The low suspended-sediment concentrations observed during peak streamflow also indicate that virtually all the sediment yield is derived from channel erosion.

Sediment Yield In Relation To Timber Harvest

The effect of timber harvest on sediment yields can only be indirectly evaluated because there is no pretreatment record. Sediment yields from the logged watershed were relatively large during the years immediately following treatment. Yields in subsequent years have been considerably less even though the average annual increase in streamflow has been about 25 percent since cutting (Martinelli 1964). A statistical comparison showed no difference in mean annual sediment yields from the three watersheds for the period 1956 through 1963.

Field inspection of the Fool Creek road system in 1964 has indicated that no gross damage from erosion has occurred since treatment. Figure 9 shows examples of the most extreme gullying activity observed.

Watershed Geomorphology

Because sediment yields from the three watersheds are largely the result of the fluvial geomorphic cycle, a consideration of various geomorphic properties relating to sediment yield should logically give a better understanding of the nature of these yields.

Important geomorphic properties which influence sediment yields are:

1. Stream orders,
2. Drainage density and related parameters,
3. Amount of relief or stage in geomorphic cycle, and
4. Channel characteristics.

Stream Order Analysis

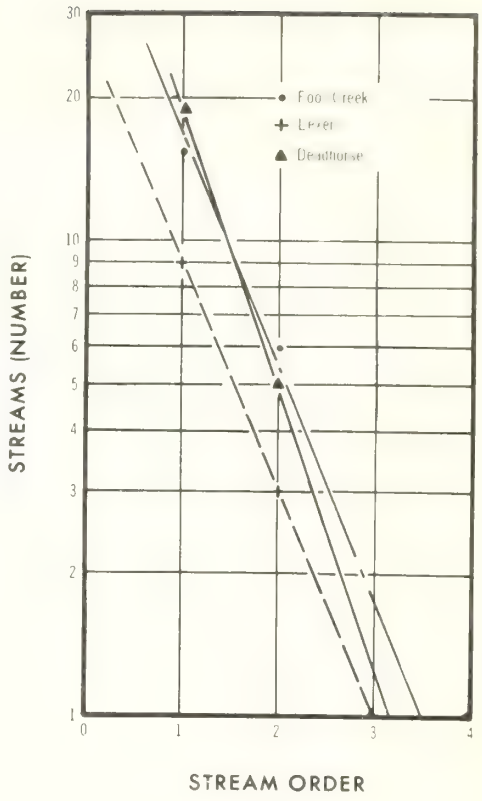
Generally, the first step in the geomorphic analysis of a given basin begins with stream order designation, following a system from Horton (1945). Horton's law of stream numbers states that the numbers of stream segments of each order form an inverse geometric sequence with order number. A regression of logarithm of number of streams of each order (ordinate) on stream order (abscissa) generally yields a straight-line plot. The antilogarithm of the slope of the line is Horton's bifurcation ratio r_b. Such curves for Fool, Deadhorse, and Lexen watersheds are shown in figure 10. The bifurcation ratios

Figure 9.--Examples of most severe erosion observed on Fool Creek watershed, Fraser Experimental Forest.

Spur roads

Main access road

Figure 10.--Regression of number of streams on stream order for Fool, Deadhorse, and Lexen watersheds.



for the three watersheds have the values 4.0, 3.2, and 3.0, respectively.

Strahler (1957) indicates that the bifurcation ratio is a very stable number, and shows a small range of variation for all regions regardless of environment. Furthermore, the ratios of second-order to third-order streams range from 2.8 to 4.9. The ratios computed from figure 10 are in good agreement with these criteria.

Drainage Density

Horton defines drainage density as the sum of the channel lengths of all orders divided by basin area. This yields a number with the dimension of inverse of length. Drainage density is of primary importance in landform scale analysis. It is reasonable to expect that sediment yield follows a close positive relationship with drainage density. Strahler has indicated that low drainage densities in the order of 3 to 8 miles per square mile are associated with erosion-resistant basins, whereas drainage densities on the order of 200 to 900 miles per square mile indicate very unstable basins with high sediment production. The values computed for Fool, Deadhorse, and Lexen watersheds are in line with these figures. They are respectively: 4.8, 8.3, and 6.5 miles per square mile.

Constant of Channel Maintenance

The inverse of drainage density has been used by Schumm (1956) as a property termed "constant of channel maintenance." This constant gives an indication of the average area necessary to maintain one unit of channel length. A typical constant of channel maintenance for the Perth Amboy badlands is 8.7 square feet per foot length, whereas in the California San Gabriel Mountains, about 316 square feet of surface are required to maintain 1 foot of channel length (Schumm 1956). Constants of channel maintenance for Fool, Deadhorse, and Lexen watersheds are 1,070, 612, and 765 square feet of surface per foot of channel length, respectively.

Hypsometric Analysis

Strahler has proposed hypsometric analysis that can be applied to a given drainage basin to determine how its mass is distributed from base to top. Two dimensionless variables are involved, relative height and relative area. Taking the drainage basin to be bounded by vertical sides and a horizontal base plane passing through the mouth, the relative height is the ratio of a given contour (h) to total basin height (H). Relative area is the ratio of horizontal cross-sectional area (a) to entire basin area (A). The percentage hypsometric curve is a plot of the continuous function relating relative height to relative area. Strahler indicates that two stages seem to mark the evolution of drainage systems in a fluvial cycle:

1. An early inequilibrium stage, during which slope changes take place rapidly as drainage expands, and
2. An equilibrium stage, in which a stable hypsometric curve develops and persists as relief diminishes.

A special monadnock phase may be recognized, but it is transitory and destruction of the monadnock is followed by restoration of the equilibrium form.

Dimensionless relations of horizontal cross-sectional area to elevation for Fool, Deadhorse, and Lexen watersheds are shown in figure 11. Also shown in figure 11 are the characteristic erosion cycle curves as given by Strahler. All three relationships closely approximate characteristic curves for the equilibrium or mature stage of geologic development.

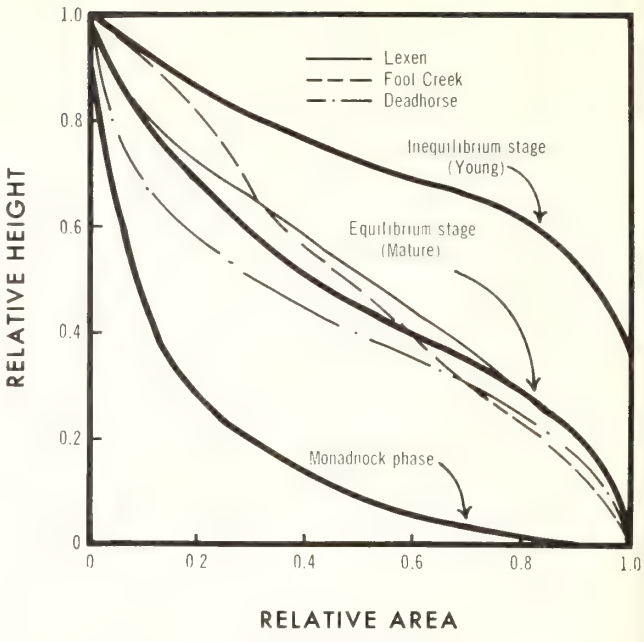


Figure 11.--Hypsometric curves for Fool, Deadhorse, and Lexen watersheds. Also, characteristic curves of erosion cycle(Strahler 1957).

Channel Profiles

An important geomorphic concept is that a stream rather early in the geomorphic cycle attains that slope or gradient which, under existing conditions of discharge and channel characteristics, is just sufficient for transportation of its load. Such a stream is said to be graded or at grade. A graded stream is not loaded to capacity; it may be either eroding or depositing. Erosion in one part of a stream channel and deposition in another part are as characteristic of a graded stream as of a nongraded one. Although a stream at grade has attained a unique gradient, it is not gradient alone that determines the graded condition. Other factors are involved, such as velocity, channel characteristics, and the nature of the material the stream has to transport. The graded condition does not imply either a high or low gradient. High-gradient streams can be in a graded condition as well as low-gradient streams.

The longitudinal profile of a graded stream is referred to as a profile of equilibrium. It is generally a smoothly concave-upward curve which decreases in slope gradually and systematically down-valley. The three study streams have this profile.

Figure 12 shows a comparison of the channel profiles of Fool, Deadhorse, and Lexen watersheds, in which the main stems are plotted to a distance of about 7,000 feet above the stream gages. The profiles plot as nearly parallel, straight lines on semilogarithmic paper, which indicates that the

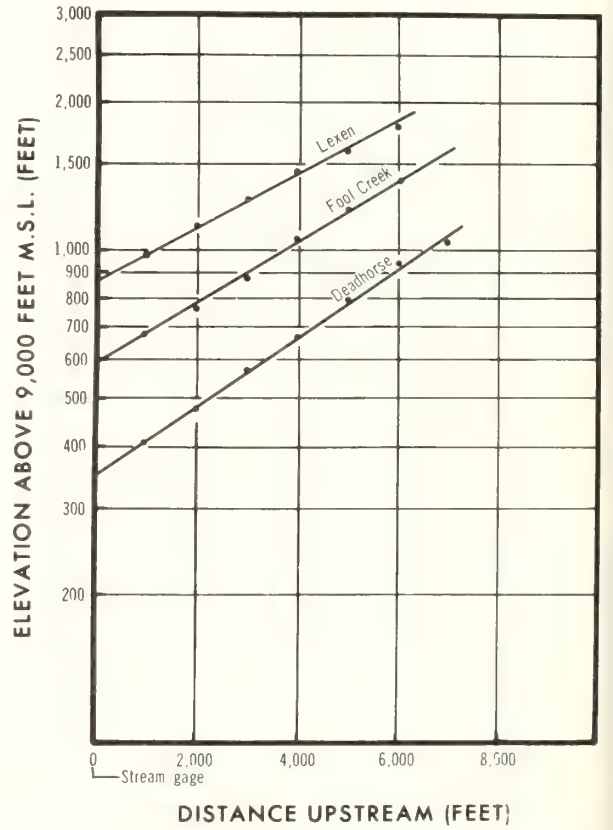


Figure 12.--Comparison of channel profiles for Fool, Deadhorse, and Lexen watersheds (semilogarithmic plot).

streams have attained profiles of equilibrium and can be considered to be graded. The low unit sediment yields also indicate that the channels have attained profiles of equilibrium.

Estimating Long-Term Sediment Yields

Sediment Yields from Small Watersheds

There is a need for sediment-yield data to define the capacity loss of water storage and diversion works on small mountain watersheds. Examples of such works are:

1. Forebay storage for power operation, and
2. Diversion storage for irrigation or municipal use.

The successful operation of such structures makes it desirable or even necessary in most cases to exclude as much of the sediment as possible. Hence, means for this exclusion must be provided for in their design. Many of these structures are located in headwater areas at high elevations or downstream from larger storage dams; the source of sediment is the natural pickup out of the main channel plus sediment inflow from intervening small drainages.

Sediment inflow from small mountainous watersheds, and the ability of the flows to move this load to the diversion point, may be quite significant during the design life of a given structure. As an example, figure 13 shows a sizable accumulation of sediment and debris behind a log jam on St. Louis Creek in the Fraser Experimental Forest. The jam is the result of logging operations in the area between 1910 and 1926 (Retzer 1962).

Calculated Risks of Annual Events--Design-Period Concept

Many hydrologic structures are commonly designed to withstand a natural event with a selected "recurrence interval" (defined as the reciprocal of the probability of exceedence). An estimate of the recurrence interval of an event usually is obtained from a cumulative frequency curve. The recurrence interval as commonly derived from the cumulative frequency curve is an average or mean value. The actual intervals of time between exceedence of a given magnitude vary widely from the mean. The mean recurrence interval has considerable meaning as a representative value and as an aid to judgment. It has even more meaning if the dispersion of the individual intervals about the mean can be determined.

Riggs (1961) has shown that the probability of an n-year event not being exceeded in an n-year period is about 0.36. Additional information regarding more than one probability of exceedence during the design period is useful for the selection of alternatives which provide for the most efficient operation of a given structure. Riggs has proposed a method for computing additional probabilities by modifying the conventional frequency curve. This is accomplished by relating the recurrence interval of an event to the probability that the magnitude of the event will not be exceeded during any selected design period. The modifications are not confidence limits on the position of the frequency curve. They provide a more complete interpretation of the frequency curve as defined by the data. By considering various magnitudes and various design periods, a system of governing risks can be calculated which provides the engineer with more flexibility in selecting an appropriate design.

To illustrate the modification procedure, a relationship is derived between magnitude of an event E and design period such that there is a 0.5 probability of not exceeding the event in the design period. Let $1-\underline{P}$ equal the probability of not exceeding $\underline{E}$ in 1 year, and let $\underline{n}$ equal the number of years. Then

$$(1 - P)^n = 0.5 \qquad (1)$$

Values of $\underline{P}$ and corresponding recurrence intervals computed by the foregoing equation are summarized below for several design periods:

Design period	Probability, P	Recurrence interval, 1/P
2	0.293	3.4
3	.206	4.9
5	.129	7.8
10	.067	14.9
20	.034	29.4

Looking downstream

Figure 13.--Sediment accumulation behind log jam on St. Louis Creek, Fraser Experimental Forest.

Looking upstream

These results indicate that the 3.4-year event from the cumulative frequency curve is the one that has a 0.5 probability of not being exceeded in a single 2-year period. Likewise, the 29.4-year event from the frequency curve has a 50-50 chance of being exceeded during a design period of 20 years.

These results may be used to modify a frequency curve by plotting the magnitude of the 3.4-year recurrence interval event at the 2-year design period, the 7.8- at the 5, the 14.9- at the 10, and so forth. Similar adjustments for different probabilities P can be computed by substituting the desired probability instead of 0.5 in formula (1) and recomputing P and recurrence interval.

The method is limited by the assumption that the magnitude-frequency relationship is exactly defined to large recurrence intervals. In actual practice, a curve based on a small sample must be used, hence the results are only as good as the data.

Use of Design-Period Concept in Estimating Annual Sediment Yields

Combined average annual sediment yields from Deadhorse and Lexen watersheds are plotted as a cumulative frequency curve in figure 14. The curve is based on the period 1956-65 as summarized for both watersheds in table 1. The vertical scale is logarithmic and shows average annual sediment yields in cubic feet per square mile ($ft.^3/mi.^2$). The horizontal scale follows the normal probability law. It shows the recurrence interval in years when applied to the solid frequency curve. The horizontal scale also shows the design period in years when applied to the dashed lines. These dashed lines show mean annual accumulated sediment determined by the modification procedure discussed in the previous section of this paper.

Figure 14 clearly indicates that, no matter what design period is used, there is still an appreciable probability of experiencing a larger event in that period. This is often overlooked in interpreting the conventional frequency curve.

Despite the fact that the observed unit sediment yields from the two watersheds were quite small, figure 14 suggests that significant accumulations of sediment can be expected at a diversion point. For example, the 10-year recurrence interval accumulation is about 600 cubic feet per square mile. During a 10-year period, however, there is an even chance that the highest sediment yield will exceed 700 cubic feet, and a 30 percent chance that it will exceed 850 cubic feet per square mile.

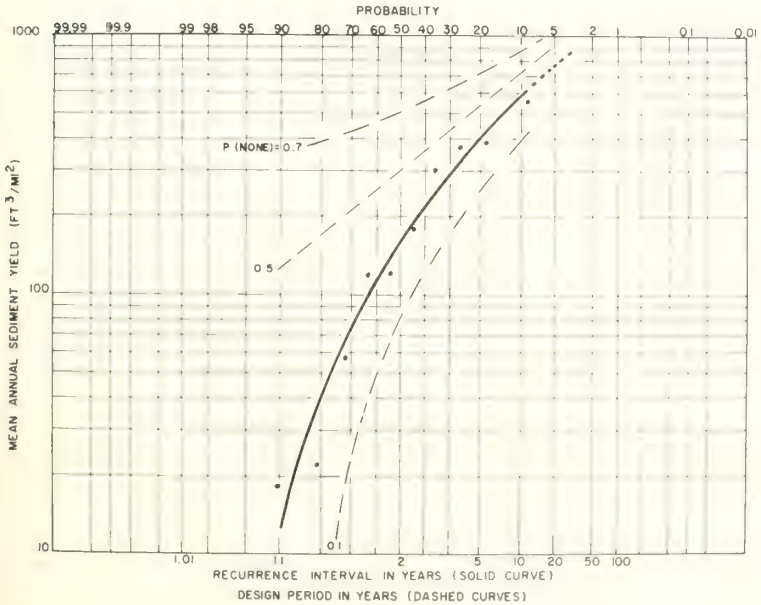


Figure 14.-- Frequency and yield probability curves for mean annual accumulated sediment from Deadhorse and Lexen watersheds.

Although the probability of experiencing no exceedences during the design period is generally of primary interest, it is sometimes desirable to know the probabilities associated with other outcomes. This is particularly true in the design of sediment detention or exclusion works, where designs are not necessarily based on extreme events. The probability for any number of exceedences during the design period can be computed by the binomial equation. Riggs computed these additional probabilities for several sizes of events and for five design periods (table 3). Whereas the probability of not exceeding 700 cubic feet per square mile once in the next 10 years is 0.5, the probabilities of experiencing exactly 1, 2, or 3 years with accumulations greater than 700 cubic feet during this period are 0.36, 0.12, and 0.02, respectively. It can also be seen that the probability of three or more exceedences during the next 10 years is 0.02.

Table 3.--Probability of exceedence of various events for five design periods (Riggs 1961)

Design period in years	Recurrence interval of event from frequency curve	Probability of exceedence in 1 year	Number of exceedences during design period							
			0	1	2	3	4	1 or more	2 or more	3 or more
2	2.0	0.500	0.25	0.50	0.250			0.75	0.25	
2	3.4	.293	.50	.41	.086			.50	.09	
2	7.5	.134	.75	.23	.018			.25	.02	
5	4.13	.242	.25	.40	.255	0.082	0.0130	.75	.35	0.095
5	5.0	.200	.33	.41	.205	.051	.0064	.67	.26	.055
5	7.8	.129	.50	.37	.110	.016	.0013	.50	.13	.020
5	17.8	.056	.75	.22	.026	.002	.0001	.25	.03	.004
10	7.7	.130	.25	.37	.250	.100	.0273	.75	.38	.130
10	10.0	.100	.35	.39	.194	.057	.0112	.65	.26	.066
10	14.9	.067	.50	.36	.116	.022	.0028	.50	.14	.024
10	35.7	.028	.75	.22	.028	.002	.0001	.25	.03	.002
20	14.9	.067	.25	.36	.245	.105	.0319	.75	.39	.145
20	20.0	.050	.36	.38	.189	.059	.0133	.64	.26	.071
20	29.4	.034	.50	.35	.118	.025	.0028	.50	.15	.032
20	71.0	.014	.75	.21	.030	.003	.0002	.25	.04	.010
40	29.4	.034	.25	.35	.242	.110	.0352	.75	.40	.158
40	40.0	.025	.36	.37	.185	.060	.0143	.64	.27	.085
40	59.0	.017	.50	.34	.118	.026	.0041	.50	.16	.042
40	139.0	.007	.75	.21	.030	.003	.0002	.25	.04	.010

Summary and Conclusions

Annual sediment yields were studied from one carefully logged and two undisturbed watersheds in the Fraser Experimental Forest, Colorado. The watersheds were described in part by evaluation of selected geomorphic characteristics.

The watersheds are very stable and characterized by coarse drainage texture and mature topography. The profiles of the main channels indicate they are in a graded condition. Results of particle-size analyses indicate that trapped sediments can be classified into three distinct sediment groups:

1. Well graded gravel with little or no fines,
2. Poorly graded sand with little or no fines, and
3. Silty or fine sand.

The coarse nature of the trapped sediments and observations of suspended sediment during peak flows (less than 5 p.p.m. in 1964 and 1965) indicate that the trap efficiencies of the debris basins are very nearly 100 percent.

A good correlation exists between annual peak discharge and annual accumulated sediment on all three watersheds. Sediment yields from these watersheds are also highly correlated with total annual flows. The relationships indicate that a major portion of the total sediment load is composed of bed material derived from streambank erosion and channel degradation. This conclusion is also supported by the low suspended-sediment concentration observed at the outflow of each debris basin during peak streamflow.

Sediment yields from the logged watershed were relatively large during the years immediately after treatment. Yields in subsequent years have been considerably less even though the average annual increase in streamflow has been about 25 percent since cutting. Mean annual sediment yields from the three watersheds were compared statistically for the period 1956 through 1963. Differences between means were not significant.

Magnitude-frequency relationships based on combined data from two of the three watersheds were developed for estimating long-term sediment yields. The design period concept shows that on a long-term basis, significant accumulations of sediment can be expected at a diversion point.

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1966 U.S. Forest Service Research Paper RM-24

Site Indexes for Lodgepole Pine, with Corrections for Stand Density:

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Instructions for Field Use

by Robert R. Alexander

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

U. S. Forest Service Research Paper RM-24 1966

SITE INDEXES FOR LODGEPOLE PINE, WITH CORRECTIONS FOR STAND DENSITY:

Instructions for Field Use

by

Robert R. Alexander, Principal Silviculturist

Rocky Mountain Forest and Range Experiment Station[1]

[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

Site Indexes for Lodgepole Pine, with Corrections for Stand Density: Instructions for Field Use

by

Robert R. Alexander

Lodgepole pine (Pinus contorta Dougl.) commonly grows in overly dense stands, and crowding restricts the rate of height growth. Site index must, therefore, be adjusted for stand density. Figures 1 and 2, and tables 1 through 7 have been prepared for field use in estimating site index for lodgepole pine. They are applicable to lodgepole pine stands in Colorado, Wyoming, Utah, Idaho, Montana, and eastern Washington and Oregon.[2] Information necessary to understand field application of the site index curves and instructions for their use are presented in this paper. Methodology used to develop the site index curves will be presented in a subsequent paper.

Stand density is expressed as Crown Competition Factor (CCF).[3] CCF compares growing space available to a tree with the space represented by a vertical projection of the average crown area of an open-grown tree of the same stem diameter (Maximum Crown Area, MCA). Because space occupied by a single tree is not easily determined, the comparison is made on a stand basis. CCF may be obtained from the numbers and diameters of trees in a stand, or it may be estimated from measurements of basal area and average diameter.

Site index is expressed as the average height of dominant trees in pure, even-aged stands at age 100 years. For stands where the CCF is 125 or less, height growth is unaffected by density. For stands where the CCF is greater than 125, height growth is reduced as density increases, and the reduction in height growth at any level of CCF above 125 becomes greater as site quality improves.

Site index can be estimated from tables 1 through 5 for all combinations of height, age, and density indicated in the Rocky Mountain and Intermountain regions, providing the average height of the trees selected for site determination is equal to or exceeds the height of the site index 30 class but does not exceed the height of the site index 100 class at the age sampled. Figure 1 can be used if the CCF is 125 or less. In the Pacific Northwest region, site index can be estimated reliably only if the "site trees" are 50 or more years old.

Field Application of Site Index Curves

Step 1.--Determine average height and age of the stand. Select four or more dominant trees (site trees) and measure heights and ages in the conventional manner.[4] Average total age may be approximated from age at breast height by adding 9 years to the average age at breast height (fig. 1 and all tables are based on total age).

[2] *This paper is based on a cooperative study planned and undertaken jointly by the Rocky Mountain, Intermountain, and Pacific Northwest Forest and Range Experiment Stations. David Tackle (INT) and Walter G. Dahms (PNW) collected the field data in their respective areas.*

[3] *Krajicek, John E., Brinkman, Kenneth A., and Gingrich, Samuel F. Crown competition factor, a measure of density. Forest Sci. 7: 35-42. 1961.*

[4] *Chapman, Herman H. and Meyer, Walter H. Forest mensuration, Chap. 15, "The measurement of heights in standing trees," pp. 149-212 and Chap. 23, "The age of standing trees," pp. 318-323. New York: McGraw-Hill Book Co. 1949.*

Step 2.--Determine the CCF of the stand in which the "site trees" developed. Two alternative methods of obtaining CCF are suggested.

A. Estimate CCF from measurements of stand diameters at breast height.

1. Establish a density plot for each "site tree." It will be a fixed-radius plot centered on the "site tree" or close enough to the "site tree" to accurately estimate the stand density in which the "site tree" developed. Plot sizes are suggested in table 6. Plots for any group of four "site trees" should be the same size. Plots may overlap, so some trees may occur in more than one plot, and may, therefore, have to be tallied more than once.

2. Measure the diameters at breast height of all trees on the density plots, and record by 1-inch classes. It is not necessary to keep the data from the four density plots separate, but care must be exercised to locate the "site trees" and density plots that make up any sampling group in a part of the stand where density is representative, and where average spacing between trees and the average diameter of those trees are similar.

3. Multiply the number of trees in each diameter class by the MCA for that diameter class (MCA constants for each diameter class for lodgepole pine are given in column 2, table 7).

4. Sum the MCA values and convert to an acre basis. The resulting value is the CCF of the stand.

5. An example of the procedure outlined in step 2A, items 3 and 4, is shown in table 7 for a typical lodgepole pine stand.

B. Estimate CCF from measurements of basal area and average diameter.

1. Determine average basal area of the stand.
   a. Select the prism with the appropriate Basal Area Factor (BAF) for the density of the stand to be sampled.
   b. Count all trees that are "in" at each sample point. Each sample point should be sufficiently close to each "site tree" to permit a valid estimate of CCF around the "site tree."
   c. Total the trees counted at the sample points, and average to determine the average number for the plot.
   d. Multiply the average per plot by the appropriate BAF. The resulting value is basal area per acre.

2. Obtain an estimate of average diameter. There are many methods available for determining average diameter. The rule-of-thumb procedure described here is rapid and accurate for the purpose intended.
   a. Walk through the stand sampled, and select what appears to be a tree of average diameter.
   b. Lay out a transect line across the stand that passes close to each "site tree."
   c. Measure the first 10 trees along this line that appear to the observer to be of average diameter.
   d. Sum those diameters and obtain an arithmetical average. That value is the estimate of average diameter.

3. Determine the $BA/\overline{D}$ Factor by dividing the average basal area per acre by the average diameter.

4. Determine estimated CCF by substituting the $BA/\overline{D}$ Factor into the equation:

$$CCF = 50.58 + 5.25 (BA/\overline{D})$$

where

CCF = Crown Competition Factor
BA = Average basal area per acre
D = Average diameter

or obtain from figure 2.

Step 3.--Determine site index.

A. Select the appropriate height-age table, based on the CCF determined in Step 2 (if CCF is 125 or less, fig. 1 may be used in place of table 1).

B. Enter the appropriate height-age table with the average dominant height and age from Step 1. Determine site index in the conventional manner; interpolate where necessary.

Specifications for Stands and Site Trees

The following specifications, upon which figures 1 and 2 and tables 1 to 7 are based, are included to provide field users with a guide to the kinds of stands and site trees to be selected for sampling.

Stands:

1. Even-aged--not more than 20 years' spread in the age of dominant trees.
2. At least 30 years old, but not more than 200 years old. (At least 50 years old in Pacific Northwest.)
3. Apparent site the same throughout the stand. Site will be considered the same if all trees are growing on similar topography, slope, aspect, and soils.

Site Trees:

1. Located in an area in the stand where present density is uniform, and there have been no abrupt changes in past density.
2. Dominants that appear to have been dominant throughout their lives. (Dominants with a normal pattern of ring widths from pith to cambium to demonstrate that they have been free to grow throughout their lives, and no changes are likely to have occurred in their relative position in the crown canopy.
3. Reasonably free of dwarfmistletoe or other diseases or injuries that may reduce height growth.
4. Sound enough for ring counts.
5. Show no visible evidence of crown damage, or tops that are broken, forked, and so forth.

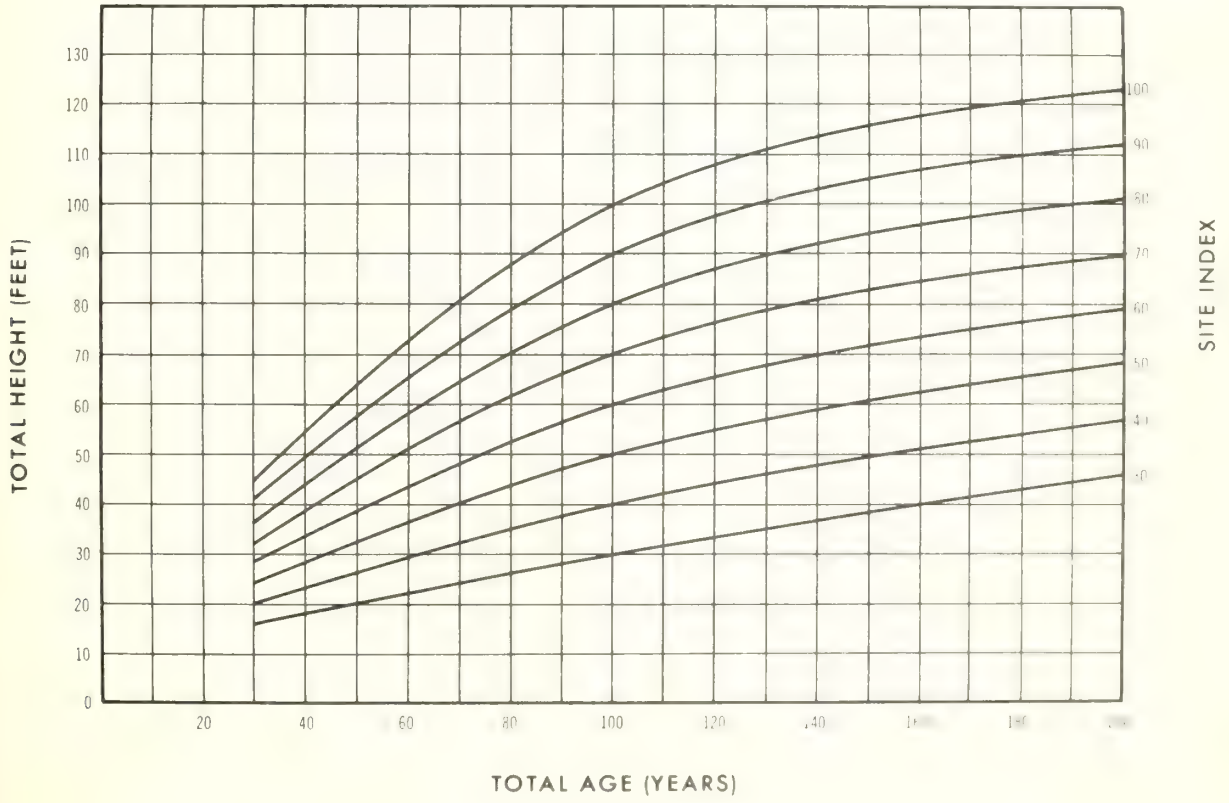

Figure 1.--Lodgepole pine site index curves for CCF 125 or less.

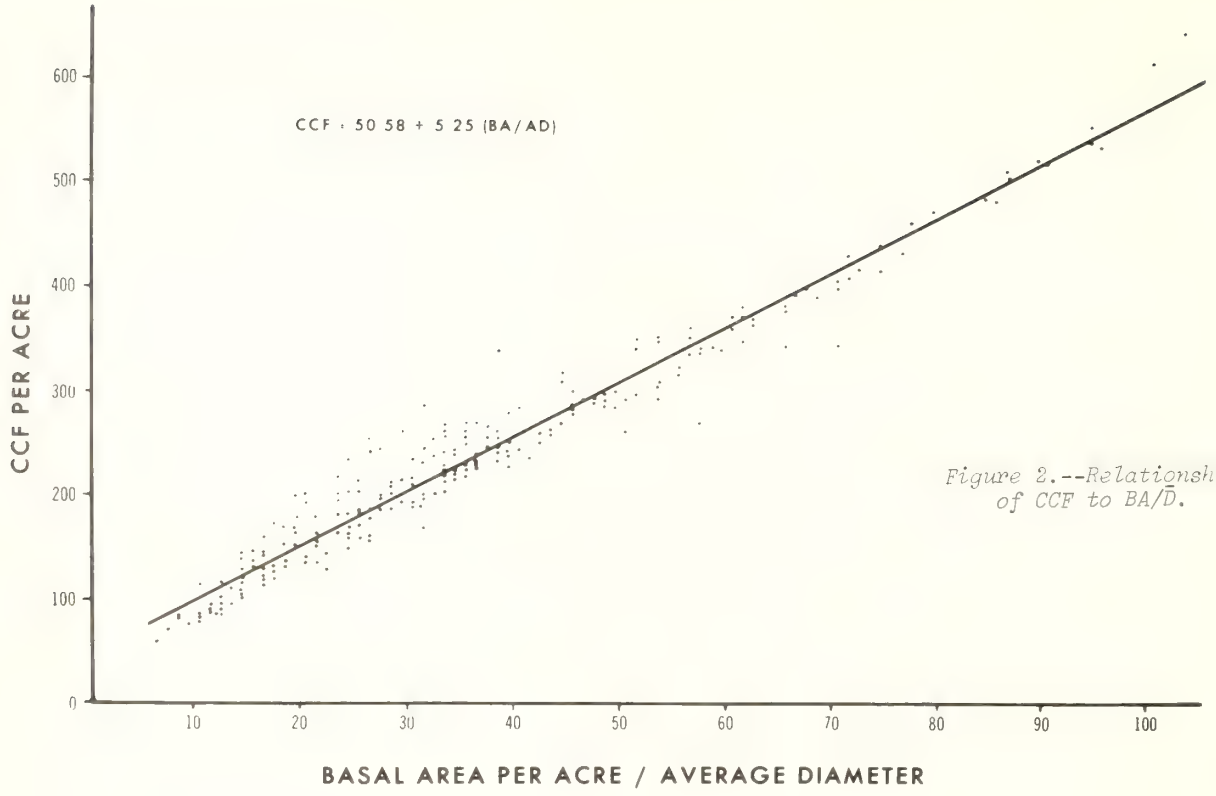

Figure 2.--Relationship of CCF to BA/D.

Table 1.--Heights of dominant trees at CCF levels of 125 or less for site index classes 30 to 100 by decadel ages 30 to 200 years

Total age (Years)	Site index class							
	30	40	50	60	70	80	90	100
	Height in feet							
30	16	20	24	28	32	36	40	45
40	18	23	28	34	39	44	49	55
50	20	26	32	39	45	51	58	64
60	22	29	36	44	51	58	65	72
70	24	32	40	48	56	64	72	80
80	26	35	44	52	61	70	79	88
90	28	37	47	56	66	75	85	94
100	30	40	50	60	70	80	90	100
110	32	42	52	63	73	84	94	104
120	34	44	55	66	76	87	98	108
130	35	46	57	68	79	90	101	111
140	37	48	59	70	81	92	103	114
150	39	50	61	72	83	94	105	116
160	40	51	62	73	84	96	107	118
170	42	53	64	75	86	97	108	119
180	43	54	65	76	87	99	110	120
190	45	56	67	78	89	100	111	122
200	46	57	68	79	90	101	112	123

Table 2.--Heights of dominant trees at CCF 200 for site index classes 30 to 100 by decadel ages 30 to 200 years

Total age (Years)	Site index class							
	30	40	50	60	70	80	90	100
	Height in feet							
30	14	18	21	25	28	32	35	38
40	16	21	25	30	35	39	44	48
50	18	24	29	35	41	46	52	58
60	20	27	33	40	47	53	60	66
70	22	30	37	45	52	59	67	74
80	24	32	41	49	57	65	73	81
90	26	35	44	53	62	70	79	88
100	28	37	47	56	66	75	84	94
110	30	40	49	59	69	79	88	98
120	32	42	52	62	72	82	92	102
130	33	44	54	64	74	85	95	105
140	35	45	56	66	77	87	98	108
150	37	47	58	68	79	89	99	110
160	38	49	59	70	80	91	101	112
170	40	50	61	71	82	92	103	113
180	41	52	62	73	83	94	104	114
190	43	53	64	74	84	95	105	116
200	44	54	65	75	86	96	106	117

Table 3.--Heights of dominant trees at CCF 300 for site index classes 30 to 100 by decadel ages 30 to 200 years

Total age (Years)	Site index class							
	30	40	50	60	70	80	90	100
	Height in feet							
30	12	14	17	20	22	25	28	30
40	14	17	21	25	29	33	36	40
50	16	21	25	30	35	40	45	50
60	18	24	29	35	41	47	52	58
70	20	26	33	40	46	53	59	66
80	22	29	36	44	51	59	66	73
90	24	32	40	48	55	64	72	80
100	26	34	43	51	60	69	77	86
110	27	36	45	54	63	72	81	90
120	29	38	48	57	66	75	85	94
130	31	40	50	59	69	78	88	97
140	33	42	52	61	71	81	90	100
150	34	44	54	63	73	83	92	102
160	36	46	56	65	75	84	94	103
170	38	47	57	66	76	86	95	105
180	39	49	58	68	77	87	97	106
190	40	50	59	69	79	88	98	108
200	41	51	61	70	80	90	99	109

Table 4. --Heights of dominant trees at CCF 400 for site index classes 30 to 100 by decadel heights 30 to 200 years

Total age (Years)	Site index class							
	30	40	50	60	70	80	90	100
	Height in feet							
30	9	11	13	15	17	18	20	22
40	11	14	17	20	23	26	29	32
50	13	17	21	25	29	33	37	41
60	15	20	25	30	35	40	45	50
70	17	23	29	35	40	46	52	58
80	19	26	32	39	45	52	59	65
90	21	28	36	43	50	57	64	72
100	23	31	39	46	54	62	70	77
110	25	33	41	49	57	66	74	82
120	27	35	44	52	60	69	77	86
130	28	37	46	54	63	72	80	89
140	30	39	48	56	65	74	83	92
150	32	41	49	58	67	76	85	94
160	34	42	51	60	69	78	86	95
170	35	44	53	61	70	79	88	97
180	36	45	54	63	72	81	89	98
190	38	47	55	64	73	82	91	99
200	39	48	57	65	74	83	92	101

Table 5. --Heights of dominant trees at CCF 500 for site index classes 30 to 100 by decadel heights 30 to 200 years

Total age (Years)	Site index class							
	30	40	50	60	70	80	90	100
	Height in feet							
30	7	8	9	10	11	12	13	14
40	9	11	13	15	17	20	22	24
50	11	14	17	20	24	27	30	33
60	13	17	21	25	29	33	38	42
70	15	20	25	30	35	40	45	50
80	17	23	28	34	40	45	51	57
90	19	25	32	38	44	51	57	63
100	21	28	35	42	48	55	62	69
110	23	30	37	44	52	59	66	74
120	24	32	40	47	55	62	70	78
130	26	34	42	49	57	65	73	81
140	28	36	44	52	59	67	75	83
150	29	37	45	53	61	69	77	85
160	31	39	47	55	63	71	79	87
170	33	41	49	57	65	73	81	89
180	34	42	50	58	66	74	82	90
190	35	43	51	59	67	75	83	91
200	36	44	52	60	68	76	84	92

Table 6. --Sizes of density plots to use for different maximum heights of site trees

Maximum height of site trees (Feet)	Plot radius	Plot size
	Feet	Acre
Unlimited	52.67	0.2
75	37.25	.1
53	26.33	.05
37	18.67	.025
24	11.75	.01
17	8.33	.005
12	5.92	.0025

Table 7. --MCA values for each diameter class, and sample computations of total MCA and CCF for a lodgepole pine stand

Diameter class	MCA[1] per tree	Number of trees	Total MCA	Sample computations
1	0.040			
2	.067			Plot size = 0.8 acre
3	.102			
4	.145			
5	.194			Total MCA = 159.6
6	.251			
7	.315	23	7.245	$CCF = \frac{\text{Total MCA}}{\text{Area in acres}}$
8	.387	41	15.867	
9	.466	37	17.242	
10	.552	47	25.944	$CCF = \frac{159.6}{0.8} = 199.5$
11	.645	50	32.250	
12	.746	30	22.380	
13	.854	24	20.496	
14	.969	12	11.628	
15	1.092	6	6.552	
			159.604	
16	1.222			
17	1.359			
18	1.504			
19	1.655			
20	1.814			

[1] Computed from equation, $MCA = 0.00365 D^2 + 0.01676 D + 0.01925$

Alexander, Robert R.
1966. Site indexes for lodgepole pine, with corrections for stand density: Instructions for field use. U. S. Forest Serv. Res. Paper RM-24, 7 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 80521.

Figures and tables are presented for estimating corrected site index of lodgepole pine. Site indexes are adjusted for stand density on the basis of data from Colorado, Wyoming, Utah, Idaho, Montana, and eastern Washington and Oregon. Methodology used to develop the curves will be in a subsequent paper.

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Indicators and Associated Decay of Engelmann Spruce in Colorado

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Thomas E. Hinds and
Frank G. Hawksworth

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

(ABOVE)

A sporophore of Fomes pini formed on tree trunk.

(COVER)

Six-log Engelmann spruce exhibiting cull indicators in upper crowns. Trees (left to right) contain:

Dead leader,
Dead top with adjacent dead rust brooms,
Live rust brooms,
Broken top.

U. S. Forest Service Research Paper RM-25 1966

INDICATORS AND ASSOCIATED DECAY OF ENGELMANN SPRUCE IN COLORADO[1]

by

Thomas E. Hinds, Associate Plant Pathologist,

and

Frank G. Hawksworth, Principal Plant Pathologist,

Rocky Mountain Forest and Range Experiment Station[2]

[1] Acknowledgment and appreciation are expressed to the Division of Timber Management, Denver Regional Office of the U.S. Forest Service, and the staffs and rangers on the National Forests for assistance in this study; and to the personnel of the Forest Disease Laboratory, Laurel, Maryland, for identifying cultures of decay fungi.

[2] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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Indicators and Associated Decay of Engelmann Spruce in Colorado

by
Thomas E. Hinds and Frank G. Hawksworth

Engelmann spruce-subalpine fir is one of the important forest types in the Central Rocky Mountains, and is the most extensive type in Colorado. Engelmann spruce is usually the predominant species. Most spruce-fir stands are mature to overmature.[3] Extensive stands are found in western Colorado between 9,000 and 11,000 feet, but the type extends from 8,000 to 11,500 feet.[4]

Mature spruce sawtimber trees vary from two to five logs (log length of 16 feet) in merchantable height throughout most of the range, but often grow to a height of as much as eight logs on the San Juan National Forest in southwestern Colorado.

Cutting was relatively limited prior to about 1950. Since then Engelmann spruce has been the leading species in lumber production, and in 1962 the spruce saw-log cut of 89 million board feet amounted to almost half of the State's output for all species.[5]

This study was undertaken to determine (1) what abnormalities are indicative of decay in Engelmann spruce in Colorado, (2) the amount of cull associated with such indicators,[6] and (3) the identification of the fungi responsible for decay.

Review of Previous Work

In 1950, Hornibrook[7] published the only previous report on the determination of decay in Engelmann spruce in Colorado by external indicators. This study, which also included lodgepole pine and subalpine fir, was based primarily on dissection of trees on the Fraser Experimental Forest, with supplemental work at some other localities on the Arapaho National Forest. Most of the cull in the study was associated with relatively few defect indicators. In order of importance they were: Conks or fruiting bodies, swollen knots, sound produced when a tree was pounded, decay on

[3] *LeBarron, R. D., and Jemison, G. M. Ecology and silviculture of the Engelmann spruce-alpine fir type. J. Forest. 51: 349-355, illus. 1953.*

[4] *Alexander, R. R. Silvical characteristics of Engelmann spruce. U. S. Forest Serv., Rocky Mountain Forest and Range Exp. Sta., Sta. Pap. 31, 20 pp., illus. 1958. Ft. Collins, Colo.*

[5] *Miller, Robert L., and Choate, Grover A. The forest resource of Colorado. U. S. Forest Serv., Res. Bull. INT-3, 54 pp., illus. 1964. Intermountain Forest and Range Exp. Sta., Ogden, Utah.*

[6] *Cull is usually considered ... size ... limbyness, rot, or other defect. That is, cull ... volume made to adjust for defect. Cull ... in this ..., and does not include loss of volume due to other ...*

[7] *Hornibrook, E. M. Estimating defect in mature and overmature stands of three Rocky Mountain conifers. J. Forest. 48: 408-417, illus. 1950.*

an increment core, fire scars, forks, cankers, frayed branch stubs, lightning scars, frost and wind cracks, and top injuries. By use of these indicators, Hornibrook was able to estimate net board-foot volume in a predominantly pine stand 31 percen defective within 2.5 percent. In a predominantly spruce stand, which was 15.4 percent defective, the estimated defect was within 2.2 percent. Accuracy of the defect estimates by tree species, however, was not given. The relative importance of a given indicator in each of the three species was not listed except in a few instances.

Hornibrook listed decay as responsible for 87 percent of the defect in the three tree species as a whole. Nearly three-fourths of the decay was caused by Fomes pini, and three fungi (F. pini, Polyporus circinatus, and Coniophora cerebella) accounted for about 90 percent of the decay volume. In all, 11 species of decay fungi were listed; none was listed as unknown.

Methods

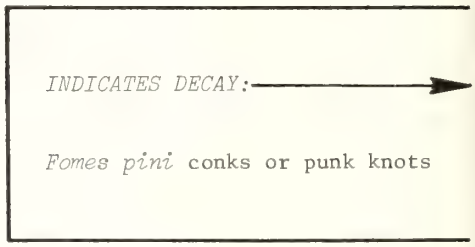
The present study was conducted in two general parts. The first part, the intensive study, involved dissection of trees with only one abnormality in a certain portion of the bole. In the second part, the extensive study, the reliability of the indicators found to be important in the intensive study were tested in commercial logging operations.

Intensive Study

Study areas usually under 20 acres in size were located throughout the spruce-fir type so that stands of different age classes and sites could be compared. The areas, usually located within a commercial sale, were selected so that the site was as uniform as possible.

From 15 to 65 trees with various abnormalities and 1 to 6 trees with no abnormalities were selected in each study area. Possible indicators of decay were recorded before and after each tree was felled. Total height, diameter at breast height, age at stump height (1 foot), and crown class were recorded for each tree. We tried to leave the sound portions of the trees in 16-foot logs, but additional cuts were made to determine the extent of any rot column. Cuts were made at all external abnormalities which were believed to be possible indicators of decay. If rot was present, we determined whether or not it was associated with the indicator. The extent of rot was delineated by cuts above and below the indicator. Complex decay columns associated with more than one indicator were discarded in calculating indicator defect Isolations were attempted whenever the causal fungus was questionable.

Inside bark and rot diameters were measured so that tree and decay volumes could be calculated on a cubic-foot and board-foot basis.



Extensive Study

In the extensive study, plots of approximately 1 acre were set up in spruce-fir sale areas just before they were cut. All trees larger than 9.6 inches in diameter were tagged. The d.b.h., crown class, and abnormalities that might indicate decay were recorded for each tree. The trees were then felled by loggers and bucked into 16-foot or smaller logs, the usual local practice. The total height was then measured to the closest foot. Inside-bark and rot diameters were measured at various points up the tree. The trees were then reconstructed on cards, and the cubic-foot gross and decay volumes calculated as in the intensive study. Board-foot gross and cull volumes were measured directly from the logs according to the regional scaling practice.

Computation Procedures

Cubic-foot volumes for each 16-foot log were determined by use of Smalian's formula:

$$\frac{A + a}{2} \times L$$

where

A = area of top cross section in square feet,
a = area of bottom cross section in square feet,
L = length in feet.

A minimum top diameter of 5.6 inches was used. This same formula was used to calculate cubic-foot decay volume if the rot extended through the log. If decay was present on only one end of the log, the rot volume was calculated as a cone.

Board-foot volumes were determined by plotting the trees on cards and marking off 16-foot logs. A 3-inch trimming allowance was made, and a top diameter of 7.6 inches was used. The top log was the largest even-foot length possible between 8 and 16 feet. Board-foot decay was calculated by using the standard squared-defect method:

$$\frac{W \times H \times L}{15} = \text{decay volume in board feet}$$

where

W and H = cross-section dimensions, in inches of the decay column (1 inch added to each dimension for waste),
L = length of decay column, in feet.

Results

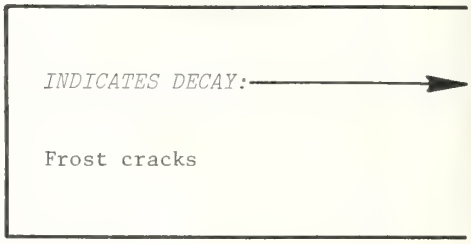
Cull Indicators

Sample plots were established in nine National Forests in Colorado. A total of 21 plots, 13 intensive and 8 extensive, with 1,027 merchantable Engelmann spruce was examined, and plot data summarized (table 1).

Over 1,300 abnormalities of 24 types were examined in the intensive study, but only 11 were found to be consistent indicators of decay. Trees in the intensive study with no abnormalities averaged 4 percent board-foot cull, so only abnormalities associated with more than 4 percent cull were considered to be decay indicators.

For the following analyses, data from the intensive and extensive studies were combined. Decay associated with indicators accounted for 86 percent of the board-foot cull and 89 percent of all cubic-foot decay. The volume of non-indicated decay was about the same in trees with and without indicators.

Eleven indicators were found to be consistently associated with decay, and the related average cull (table 2). Cull was separated on an indicator basis where the same tree was used in two or more categories. Other abnormalities that were not consistent indicators of decay in Engelmann spruce were: Butt swell, burls, crooks, dead branches, hollow buttress,[8] leaning trees, lightning scars, live rust brooms, recent dead tops, root wounds, and spruce cankers. Board-foot and cubic-foot cull associated with these indicators was less than 4 percent and 1 percent, respectively.



Trees frequently had more than one cull indicator. The proportion of trees with the various indicators in the extensive-study plots is given in table 2. As seen in the table, 43 percent of the trees on the eight study areas (total of 10.2 acres) were free of cull indicators.

[8] *Spruce at high elevations and along stream beds frequently have large lateral roots extending above the ground line near the root collar. Hollow buttress refers to the buttress-like effect characterized by the open air spaces extending beneath these roots and often a foot or more beneath the tree butt.*

Table 1.--Summary of Engelmann spruce cull indicator study plot data

Plot number	Location		Trees	Average age	Site index[1]	Abnormalities	Cull[2]
	National Forest	Ranger District	Number	Years		Number	Percent
INTENSIVE STUDY (1957-58):							
1	Roosevelt	Redfeather	59	443	65	144	--
2	Pike	Bailey	57	294	65	102	--
3	White River	Minturn	41	447	70	141	--
4	Grand Mesa - Uncompahgre	Mesa	45	139	90	89	--
5	San Juan	Mancos	57	309	70	147	--
6	San Juan	Animas	19	210	115	47	--
7	San Juan	Animas	15	213	105	48	--
8	Routt	Hahns Peak	20	223	85	44	--
9	Routt	Hahns Peak	50	243	85	104	--
10	San Isabel	San Carlos	63	312	70	144	--
11	Arapaho	Sulphur	65	253	90	185	--
12	Rio Grande	Del Norte	33	170	80	73	--
13	Rio Grande	Del Norte	24	218	95	80	--
	All intensive plots		548	--	--	1,348	--
EXTENSIVE STUDY (1959):							
14	Pike	Bailey	89	270	55	121	26
15	Pike	Bailey	19	380	55	41	10
16	Roosevelt	Laramie River	52	350	60	85	9
17	Grand Mesa - Uncompahgre	Ouray	54	165	100	108	17
18	Grand Mesa - Uncompahgre	Ouray	81	240	90	108	19
19	Roosevelt	Laramie River	58	419	75	124	15
20	Routt	Bears Ears	67	209	90	80	11
21	Routt	Bears Ears	59	172	85	89	7
	All extensive plots		479	--	--	756	15
	Total, all plots		1,027	--	--	2,104	--

[1] Based on total height and age 100 years at d.b.h. (Hornibrook, E.M. Yield of cutover stands of Engelmann spruce. J. Forest. 40: 778-781, illus. 1942.

[2] In plots 1 through 13, mostly trees with indicators were felled, so no information on average cull was obtained.

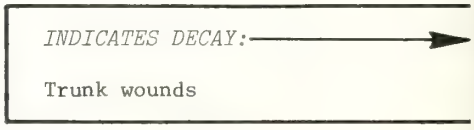


Table 2.--Indicators of decay in Engelmann spruce, and associated cull

Indicator	Extensive plots only	All plots					
	Trees with indicator	Trees	Frequency of decay	Average cull			
	Percent	Number	Percent	Board feet	Percent	Cubic feet	Percent
[illegible] punk knot [illegible] spar pheno[illegible]	2	54	100	260	81	32.7	51
Dead top with adjacent dead rust brooms	1	21	67	180	21	16.0	11
Broken top	2	32	75	90	25	8.0	12
Dead rust brooms	1	44	32	50	11	5.0	6
Frost cracks	9	181	32	50	9	4.2	3
Dead leader	7	86	34	30	11	2.6	4
Basal wounds	33	400	37	30	10	2.1	3
Spike top	5	53	30	30	8	2.9	4
Trunk wounds	23	346	23	30	5	2.2	3
All forks	11	191	25	20	8	2.1	3
Joined at base to another tree	6	77	47	20	11	1.5	4
Trees with none of above indicators	[1] 14	582	12	10	2	.4	1

[1] Includes 11 abnormalities not associated with decay (frequency of 15 percent), and trees with no indicators (frequency of 28 percent).

Cull deductions are customarily based on diameter rather than age, but this could not be done for Engelmann spruce. For this species in Colorado, diameter growth is so slow after about 150 years that there was no well-defined relationship between diameter and age.

The 11 cull indicators consistently associated with decay were divided into 3 classes, based on the average amount of cull (table 3). Cull deductions for these indicators by two age classes are also shown in the table. For all other abnormalities which were not consistent indicators of decay, and for trees with no indicators, average board-foot cull amounted to 2 percent; cubic-foot decay, 1 percent.

The sound emitted by a tree when struck at the base often indicates whether the butt log contains decay. All trees in the study were sounded as high as could be reached with a 4-pound sledge or a double-bitted axe. Hollow trees and trees with large amounts of decay in the base emitted a deep, drumlike note when struck. Trees with no basal decay gave out a sharp, ringing sound when struck, whereas trees with incipient or small amounts of decay did not clearly indicate either. The results of sounding 1,027 trees were as follows:

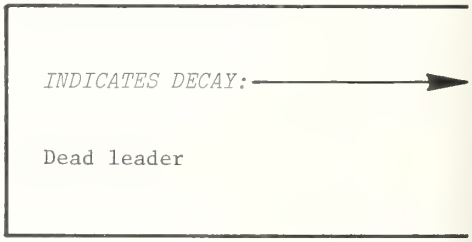
Sounding	Number of trees	Percent of trees with decay	Cull percent of butt log
Hollow	112	96	68
Suspect	383	66	36
Sound	532	30	13

Thus, while this method gives fairly reliable estimates of decay in "hollow" or "sound" trees, the high proportion of trees in the "suspect" class makes sounding of little practical use, except for indicating extensive decay in the butt log.

Fungi Associated with Cull Indicators

Decay fungi were identified for 76 percent of the infections associated with cull indicators, and 88 percent of all infections in the intensive study. The important decay fungi of Engelmann spruce, and average cull associated with them, are shown in table 4.

Cull indicators and associated decays are given in table 5. The frequency of decay fungi does not necessarily indicate their normal frequency in a stand, but rather their association with specific indicators of decay. Generally, there was little relationship between certain indicators and occurrence of specific fungi.



While butt rots accounted for only 12 percent of the decay in the intensive study, it should be noted that only trees with abnormalities were sampled. In these trees, two-thirds

Table 3.--Average board-foot cull deductions by indicator classes for merchantable Engelmann spruce

Indicator			Decay as proportion of gross volume		
			Average age of stand		All stands
Class	Type	Basis	Under 250 years	Over 250 years	
		Number	Percent	Percent	Percent
1	[illegible] punk knots or sporophores	54	68	86	81
2	Broken top or dead top with adjacent dead rust brooms	53	21	25	24
3	Basal wounds, dead rust brooms, dead leader, frost cracks, forks (all types), joined at base to another tree, spike top, and trunk wounds	1,378	8	11	10

of the butt rot was associated with specific external indicators. The proportion of decays not associated with specific cull indicators implies that some of the trees contained decay which entered through roots or by other means that were not noticed during the study. For instance, Pholiota alnicola, Polyporus tomentosus, and Armillaria mellea are known to gain entrance to a tree through its roots, but usually the decay columns do not extend upward to any great extent. The association of P. tomentosus with trunk wounds, forks, and a broken top is unusual, as are the associations of other butt-rot fungi with trunk wounds and forks.

Fomes nigrolimitatus is usually considered to be a basal decay fungus, but it was also associated with trunk wounds and caused considerable cull throughout the tree.

With the exception of Coniophora puteana and Fomes pinicola, the brown rots seldom cause extensive basal decay. C. puteana was the most frequently encountered brown rot, but F. pinicola was equally important in amount of cull. However, F. pinicola usually attacks only dead sapwood and is often associated with old, extensive basal wounds.

Trunk rots associated with cull indicators amounted to 88 percent of the decay in the intensive study. Over 90 percent of the infections were directly attributed to specific indicators. Fomes pini was the most important decay fungus associated with cull indicators. It was the only decay associated with all indicators in table 5, and because the decay was usually more extensive in the tree, it caused the greatest amount of cull. Length of decay columns and average cull of Fomes nigrolimitatus and Stereum sulcatum surpass those of S. sanguinolentum, although the latter was more frequently associated with cull indicators.

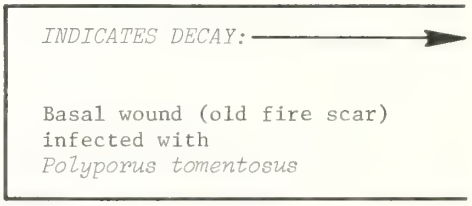


Table 4.--Important decay fungi of Engelmann spruce

Fungus	Infections		Average cull		Average decay column
	No.	Pct.	Bd.ft.	Cu.ft.	Ft.
WHITE BUTT ROTS:					
[illegible] (Lev.) Egel.	13	3	150	14.7	25
[illegible] (Fr.) Singer	18	4	90	3.7	8
[illegible] Fr. var. [illegible] (Fr.) Satory & Maire	17	4	60	3.5	10
Corticium radiosum (Fr.) Fr.	11	3	50	3.3	8
[illegible] (Fr.) Cke.	4	1	20	.3	3
Pholiota sp.	3	1	20	4.7	5
BROWN BUTT ROTS:					
[illegible] (Schum. ex Fr.) Karst	19	4	70	3.3	9
C. olivacea (Fr.) Karst	6	1	10	.2	3
Fomes pinicola (Swartz) Cke.	3	1	70	3.5	15
WHITE TRUNK ROTS:					
Fomes pini (Fr.) Karst	143	34	190	21.2	35
[illegible] (Alb. & Schw. ex Fr.) Fr.	122	29	80	5.9	21
S. sulcatum Burt.	28	7	150	15.8	24
S. chailletii (Pers. ex Fr.) Fr.	7	2	50	4.3	19
BROWN TRUNK ROTS:					
Trametes serialis Fr.	6	1	50	4.0	16
Peniophora septentrionalis Laurila	6	1	30	2.1	13
Stereum abietinum Pers.	3	1	100	13.9	30
Lenzites saepiaria (Wulf.) Fr.	3	1	90	7.1	21
OTHER DECAY FUNGI[1]	8	2			
TOTAL ROTS	420	100			

[1] Fungi that constituted less than 1 percent each of the total identified infections were:
Butt rots -- *Pholiota squarrosa* (Fr.) Kummer; *Collybia velutipes* Curt. ex. Fr.; *Coniophora arida* (Fr.) Karst.; *Polyporus balsamens* Pk.
Trunk rots -- *Trechispora raduloides* (Karst.); *Poria ferrugineo-fusea* Karst.; *Fomes roseus* Alb. & Schw. ex Fr.

Field Application of Cull Indicators

The cull percentages in table 3 are averages, so they cannot be expected to give decay estimates for individual trees or small numbers of trees. We suggest that averages based on stand age be used when possible on small areas. On larger areas where stands differ or contain mixed age classes, then the average for all stands should be used.

All indicators apply to the merchantable parts of the bole only--that is, below a 6-inch top diameter. The cull deductions for each indicator should be added for the merchantable tree, unless two or more indicators occur in the same part of the bole. In this case, use the highest deduction. For example, if a broken top and fork occur on the same part of the bole, deduct only for the broken top.

The cruiser should record the gross volume of each tree, and note the number of indicators in the three classes for all trees tallied. Multiply the number of indicators in each class by the appropriate cull percent. Then divide the total of all three classes by the number of trees in the sample. To obtain the total cull deduction, add a flat cull factor of 2 percent (for other non-indicated decay).

As an example of the application of these cull data, the results for the four plots over 250 years old (table 1--plots 14, 15, 16, and 19) will be given. There were a total of 218 trees on these plots, with 266 indicators in the 3 indicator classes as follows:

Indicator class	Percentage deduction (table 3)	Number of indicators	Total deduction
1	86	7	602
2	25	8	200
3	11	251	2,761
Totals	--	266	3,563

This total of 3,563 is divided by the number of trees in the sample (218) to give a deduction of 16 percent. To this is added the flat cull factor of 2 percent, to give an estimated total cull of 18 percent. Cull based on actual measurement of decay in these plots was 18.1

Table 5.--Fungi associated with cull indicators of Engelmann spruce

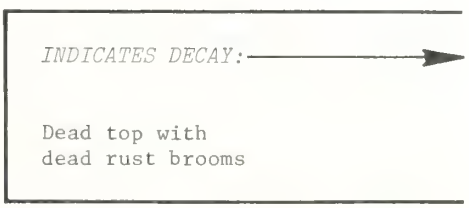
Fungus	Infections	Cull indicator										
		Dead top with dead rust brooms	Broken top	Dead rust brooms	Frost cracks	Dead leader	Basal wound	Spike top	Trunk wound	Forks	Joined base	Other[1]
		Number										
	11		1		1			1	5		2	1
Pholiota alnicola	7				1		4		1			1
	13		1		1		4		1	1	2	3
	4				1		3					
Pholiota sp.	2						1		1			
	2				1				1			
Collybia velutipes	1						1					
	16						6		6		1	3
	3						1					2
	3						1		2			
Coniophora arida	1						1					
	1									1		
	[2]137	6	7	20	2	5	5	4	8	21	8	8
	107	3	9	4	6	5	24	5	28	8		15
	28	2	1	3	5		1		3	4	4	5
	7						3		2	1	1	
	1									1		
	1									1		
	6	1	3						2			
Peniophora septentrionalis	3								3			
	3							1	1	1		
	3		1				2					
	1		1									
TOTAL	361	12	24	27	18	10	57	11	64	39	18	38

[1] Decay fungi associated with other abnormalities not listed.
[2] Includes 43 infections associated with punk knots and sporophores.

percent. Estimated and actual cull percentages for the 4 plots under 250 years old were also within 1 percent.

Board-foot cull can be obtained by the percent deductions in table 3, or by using the average board-foot cull from table 2. Cull estimates from tables 2 and 3 will give similar results, but table 3 will be easier to use in the field because it has only three indicator classes.

The number of trees to be tallied for reliable cull estimates has not been determined. The number will vary from area to area, because certain indicators are more prevalent in some stands than others. Also, some abnormalities are more reliable indicators of decay than others. For example, all trees with Fomes pini sporophores or punk knots were decayed, as were 75 percent of the trees with broken tops, but decay was associated with only 30 percent of the old, dead spike tops and 23 percent of the forked tops. Since the number of trees that need to be sampled to obtain various degrees of accuracy is not known, it is suggested that all trees on sample plots be tallied.



Summary

Information on decay and average amount of cull associated with cull indicators was obtained from over 2,000 abnormalities on 1,027 merchantable Engelmann spruce trees from 21 plots throughout spruce stands in Colorado.

Board-foot percent cull deductions for all stands by three indicator classes was found to be as follows:

Class 1--Fomes pini punk knots or sporophores (81 percent):
Class 2--broken tops or dead tops with adjacent dead rust brooms (24 percent);

DO NOT INDICATE DECAY:

← Spruce cankers

↓ Burl

Class 3--basal wounds, dead rust brooms, dead leader, frost cracks, all forks, joined at base to another tree, spike top, and trunk wounds (10 percent). A flat cull factor of 2 percent is then added to obtain the total average cull deduction.

The fungi associated with 88 percent of the infections in the intensive study were identified. Butt rots, with the exception of Fomes nigrolimitatus, were not usually extensive or associated with much cull. Fomes pini was the most important decay fungus.

Hinds, Thomas E., and Hawksworth, Frank G.
1966. Indicators and associated decay of Engelmann spruce in Colorado. U. S. Forest Serv. Res. Paper RM-25, 15 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 80521.

Average cull deductions for 11 cull indicators were determined from over 2,000 abnormalities on 1,027 merchantable Engelmann spruce in 21 stands throughout Colorado. On a board-foot basis, Fomes pini punk knots or sporophores caused an 81 percent deduction. Deduction for broken tops or dead tops with adjacent dead rust brooms amounted to 24 percent. Basal wounds, dead rust brooms, a dead leader, frost cracks, all forks, joined at the base to another tree, spike top, and trunk wounds were each responsible for a 10 percent deduction. Fomes pini was the most important decay fungus.

852:844.2:174.7 Picea engelmannii

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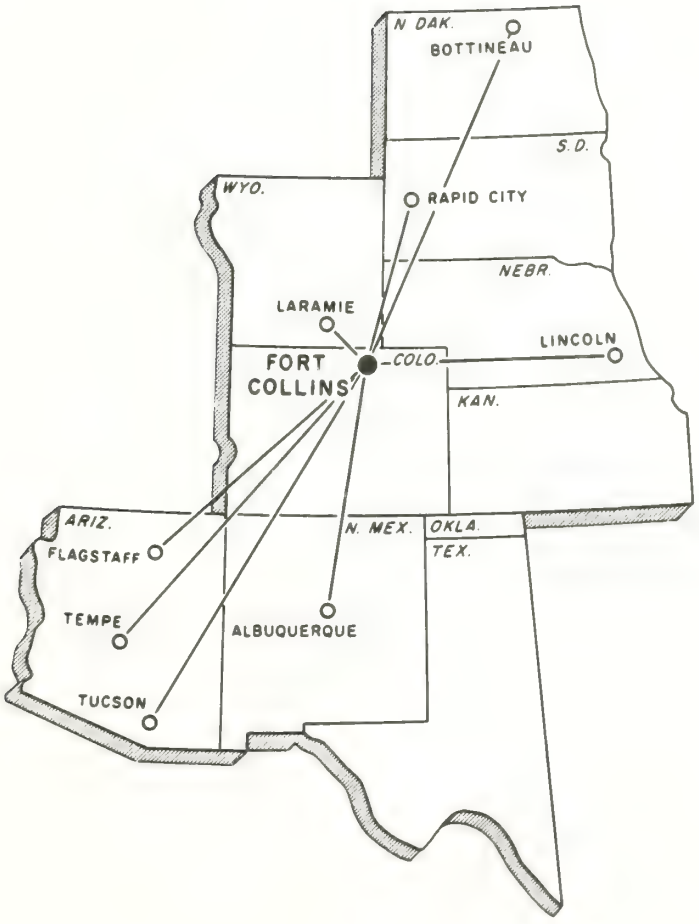
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YIELD TABLES FOR MANAGED STANDS OF Lodgepole Pine In Colorado and Wyoming

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Clifford A. Myers

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Clifford A. Myers, Principal Mensurationist

Rocky Mountain Forest and Range Experiment Station[1]

[1] Central headquarters maintained in cooperation with Colorado State University at Fort Collins.

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Yield Tables for Managed Stands of Lodgepole Pine in Colorado and Wyoming

by

Clifford A. Myers

Estimates of the growth and yield of managed stands can be obtained before managed stands are created. These estimates, compiled as yield tables, serve as guides for timber management decisions. Yields can be investigated to determine if management for timber production is a desirable goal for specific areas. Sets of yield tables can be prepared with various stocking levels, rotation lengths, and other variables subject to manipulation. How various management alternatives will affect yields can be estimated by comparing values in the tables.

An advance look at possible future returns is especially important for lodgepole pine (Pinus contorta Dougl.). This species reproduces readily and is a classic example of stagnation in growth. So much has been published on the growth of dense stands that the potential of lodgepole pine is often ignored. Amount of precipitation and length of growing season do create definite upper limits to yields in the lodgepole pine type. These limits, however, appear to be subject to increase through standard timber management techniques. Yield tables for managed stands indicate the increase possible, and the combination of management controls that can produce the desired result.

This publication presents: (1) working tools and other guides useful in the compilation of yield tables for managed, even-aged stands of lodgepole pine, and (2) examples of managed-stand yield tables. Instructions are limited to use of the working tools. Detailed explanations of how to obtain the working tools are available elsewhere.[2]

Management procedures to be examined with the yield tables may be varied within limits set by the ranges of variables used to develop the working tools. Stand age at initial thinning, stocking goals, and other management controls can be varied to determine their effect on timber production. The yield table that best describes the objectives of management becomes the standard for the forest. Similarly, each yield table reproduced here is based on one of several possible combinations of management goals. Managers of lodgepole pine who prefer other alternatives can use the working tools to compile yield tables that will describe their objectives.

Management Decisions

Several decisions must be made before yield tables can be compiled with aid of the working tools. As examples of the problems to be solved, the following decisions were made for the yield tables presented here:

1. Stands will be regenerated by clearcutting, with most seeds coming from the serotinous cones of trees felled on the cutting area.

[2] *Myers, Clifford A. Yield tables for managed stands with special reference to the Black Hills. U.S. Forest Serv. Res. Paper RM-21, 20 p., illus. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo. 1966.*

2. Cultural operations such as slash disposal will be used to control seedling density so there will be about 2,000 well-distributed seedlings per acre when they are 10 years old.
3. Initial thinning can be delayed until the stands are 30 years old if density does not greatly exceed 2,000 trees per acre at age 10.
4. Desirable stocking levels, as defined in table 1, will usually range from 80 to 100. Various stocking levels are given in the columns of table 1. Basal area per acre increases with average diameter of the reserve stand (left column of table) until a diameter of 10.0 inches is reached. After this, stands are rethinned to the same basal area each time. For example, stands man-

Table 1.--Growing stock levels for lodgepole pine in Colorado and Wyoming. Basal areas after intermediate cutting in relation to average stand diameter.

Ave. stand d.b.h. after cutting	Growing stock level							
	50	60	70	80	90	100	110	120
Inches	Square feet per acre							
2.0	7.7	9.2	10.8	12.3	13.8	15.4	16.9	18.4
2.2	9.0	10.8	12.6	14.4	16.2	18.0	19.8	21.6
2.4	10.4	12.4	14.5	16.6	18.7	20.8	22.8	24.9
2.6	11.8	14.2	16.5	18.9	21.3	23.6	26.0	28.4
2.8	13.3	16.0	18.6	21.3	24.0	26.6	29.3	32.0
3.0	14.8	17.7	20.6	23.6	26.6	29.5	32.4	35.4
3.2	16.2	19.5	22.8	26.0	29.2	32.5	35.8	39.0
3.4	17.8	21.3	24.8	28.4	32.0	35.5	39.0	42.6
3.6	19.2	23.0	26.9	30.7	34.5	38.4	42.2	46.0
3.8	20.6	24.7	28.8	32.9	37.0	41.1	45.2	49.4
4.0	22.0	26.4	30.8	35.2	39.6	44.0	48.4	52.8
4.2	23.5	28.2	32.9	37.6	42.3	47.0	51.7	56.4
4.4	24.9	29.8	34.8	39.8	44.8	49.8	54.7	59.7
4.6	26.4	31.6	36.9	42.2	47.5	52.8	58.0	63.3
4.8	27.9	33.4	39.0	44.6	50.2	55.8	61.3	66.9
5.0	29.2	35.0	40.9	46.7	52.5	58.4	64.2	70.0
5.2	30.5	36.6	42.7	48.8	54.9	61.0	67.1	73.2
5.4	31.8	38.2	44.5	50.9	57.3	63.6	70.0	76.4
5.6	33.0	39.6	46.2	52.8	59.4	66.0	72.6	79.2
5.8	34.2	41.0	47.9	54.7	61.5	68.4	75.2	82.0
6.0	35.4	42.4	49.5	56.6	63.7	70.8	77.8	84.9
6.2	36.6	43.9	51.2	58.5	65.8	73.1	80.4	87.8
6.4	37.7	45.2	52.8	60.3	67.8	75.4	82.9	90.4
6.6	38.8	46.5	54.2	62.0	69.8	77.5	85.2	93.0
6.8	39.9	47.8	55.8	63.8	71.8	79.8	87.7	95.7
7.0	40.9	49.1	57.3	65.5	73.7	81.9	90.1	98.2
7.2	41.9	50.2	58.6	67.0	75.4	83.8	92.1	100.5
7.4	42.8	51.3	59.8	68.4	77.0	85.5	94.0	102.6
7.6	43.6	52.4	61.1	69.8	78.5	87.2	96.0	104.7
7.8	44.5	53.4	62.3	71.2	80.1	89.0	97.9	106.8
8.0	45.3	54.4	63.4	72.5	81.6	90.6	99.7	108.8
8.2	46.1	55.4	64.6	73.8	83.0	92.2	101.5	110.7
8.4	46.8	56.2	65.5	74.9	84.3	93.6	103.0	112.4
8.6	47.4	56.8	66.3	75.8	85.3	94.8	104.2	113.7
8.8	47.9	57.5	67.1	76.7	86.3	95.9	105.5	115.0
9.0	48.4	58.1	67.8	77.5	87.2	96.9	106.6	116.2
9.2	48.9	58.6	68.4	78.2	88.0	97.8	107.5	117.3
9.4	49.2	59.1	69.0	78.8	88.6	98.5	108.4	118.2
9.6	49.5	59.4	69.3	79.2	89.1	99.0	108.9	118.8
9.8	49.8	59.8	69.7	79.7	89.7	99.6	109.6	119.6
10.0+	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0

aged at stocking level 80 would be thinned to 35.2 square feet if average diameter is 4.0 inches. Each rethinning will leave 80 square feet of basal area per acre after diameter averages 10.0 inches.

Relationships shown in table 1 were developed originally for ponderosa pine.[2] They were judged to be suitable for lodgepole pine because similar intensities of thinning have been recommended for the two species.[3] [4]

Stands that conform to the first three management decisions will grow about as indicated by the following averages:

1. Stands with about 2,000 trees per acre at age 10 will contain about 1,700 trees at age 20, regardless of site quality. Total loss for the 10 years will be about 15 percent.
2. Numbers of trees per acre will be reduced by the following percentages as stand age increases from 20 to 30 years:

Site index	Reduction (Percent)
40, 50	3
60	6
70, 80	9

Similar reductions will occur over a range of 1,200 to 1,700 trees per acre at age 20.

3. Average stand diameter before thinning at age 30 will be as follows:

Site index	Diameter (Inches)
30	2.6
40	2.9
50	3.2
60	3.4
70	3.6
80	3.8

As mentioned previously, management decisions for particular areas may differ from those given here. Numbers of trees and average diameters that relate to other objectives can be determined on temporary plots, if necessary. The working tools presented below will remain useful so long as even-aged stands and thinning from below are retained in management prescriptions.

Working Tools

Six working tools are used to compile yield tables for managed, even-aged stands of lodgepole pine. Three tools provide predictions of future changes in a stand due to growth or thinning. One serves as a check to insure that realistic projections are made. Two tools permit conversion of stand density and height to stand volumes in various units.

Periodic Increase In Stand Diameter

Future average stand diameter can be estimated from the following relationship:

$$D_f = 2.1450 + 1.0222\, D_p - 1,2417 \log B_p + 0.0151\, S \qquad \text{(Equation 1)}$$

where:

D_f = average stand diameter in 10 years, in inches,
D_p = present stand diameter, in inches,
B_p = present basal area per acre, in square feet,
S = site index for lodgepole pine.[5]

Absence of thinning, fire, or other disturbance during the 10-year prediction period is assumed.

This relationship is applicable to even-aged stands of lodgepole pine with stocking levels of 50 to 170 at the beginning of the prediction period. Diameters sampled ranged from 2 to 12 inches; site indexes ranged from 30 to 76.

[3] *Alexander, Robert R. Thinning lodgepole pine in the Central Rocky Mountains. J. Forest. 58: 99-104, illus. 1960.*

[4] *Myers, Clifford A. Thinning improves development of young stands of ponderosa pine in the Black Hills. J. Forest. 56: 656-659, illus. 1958.*

[5] *Alexander, Robert R. Site indexes for lodgepole pine, with correction for stand density: Instructions for field use. U. S. Forest Serv. Res. Note RM-24, 7 p., illus. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo. 1966.*

Limited extrapolation to larger diameters is possible and cannot be avoided at present. Well-stocked stands with average diameter larger than 12 inches that were also younger than about 200 years could not be found. Comparison with a similar prediction equation for ponderosa pine indicated that increase in the range of D_p sampled would not change the form of the equation above. Material change in the values of the regression constants appeared unlikely. Extrapolations for the yield tables (tables 5 to 14) were therefore made well beyond what might otherwise be done.

Diameter Increase From Thinning

Thinning from below will increase average stand diameter, regardless of changes caused by tree growth. Initial thinning to a desired stocking level will produce a relatively large increase. Rethinning to the same level to which the stand was thinned previously will result in a smaller change. Both increases are large enough to require consideration in growth predictions.

Rethinning an even-aged stand to the same growing stock level to which it was thinned 10 years previously will increase average diameter 0.3 inch. Rethinning after 30 years will increase diameter 0.5 inch. These changes occurred in stands with growing stock levels between 60 and 150.

Increase in average diameter caused by initial thinning of young stands with 1,200 to 4,400 trees per acre can be determined from table 2. Instructions for construction of such tables are available elsewhere.[6] To predict diameter changes, follow this procedure:

1. Determine the growing stock level to which the stand is to be thinned.
2. On a sheet of cross-section paper, plot basal areas from the appropriate column of table 1 over the corresponding diameters. Connect the points with a smooth line; this is the stocking line. Consider only the range of diameters within which diameter after thinning is expected to fall, such as from 2.5 to 4.5 inches.
3. From table 2 obtain the diameter after thinning that corresponds to initial diameter, and the estimated percentage of trees to be retained. For example, average stand diameter increases from 2.9 to 4.0 inches if 25 percent of the trees remain uncut.
4. Compute the basal area of the trees retained when average diameter is the after-thinning value read in step 3. For example, 25 percent of 1,650 trees, or 412.5 trees, have a basal area of 36.0 square feet when average diameter is 4.0 inches.
5. Plot computed basal area over diameter after thinning on the graph started in step 2.
6. Repeat steps 3 to 5 with a slightly different percentage of trees retained than used in step 3. Place a second point on the graph on the opposite side of the stocking line from the plotted point of step 5.
7. Draw a straight line through the points plotted in steps 5 and 6.
8. Read diameter after thinning on the horizontal axis of the graph, directly below intersection of the stocking line (step 2) and the trial line (step 7).

The plotted points of steps 5 and 6 should be as near as possible to the stocking line. A line connecting several plotted points on a single graph will only occasionally be straight. Interpolations in table 2 are unnecessary, however.

Periodic Increase In Basal Area

Future basal area per acre can be estimated from the following relationship:

$$B_f = 5.6456 + 0.9261\ B_p + 0.2146\ S + 0.0004\ NS \qquad \text{(Equation 2)}$$

where:
B_f = basal area in 10 years, in square feet,
B_p = present basal area, in square feet,
S = site index for lodgepole pine,[7]
N = present number of trees per acre.

This relationship is used to be sure that projections of diameter growth are reasonable, as described in Derivation of Yield Tables.

[6] *See footnote 2, p. 1.*

[7] *See footnote 5, p. 3.*

Table 2.--Increase in average stand diameter caused by initial thinning from below. Even-aged stands of lodgepole pine in Colorado and Wyoming.

Diameter before thinning (inches)	Percent of trees retained									
	5	10	15	20	25	30	35	40	45	50
	Diameter after thinning, inches									
2.5	4.1	3.9	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0
2.6	4.3	4.1	3.9	3.7	3.6	3.5	3.4	3.3	3.2	3.2
2.7	4.4	4.2	4.0	3.8	3.7	3.6	3.5	3.4	3.3	3.3
2.8	4.6	4.3	4.2	4.0	3.8	3.7	3.6	3.5	3.4	3.4
2.9	4.7	4.5	4.3	4.1	4.0	3.8	3.7	3.6	3.6	3.5
3.0	4.8	4.6	4.4	4.2	4.1	3.9	3.8	3.7	3.7	3.6
3.1	4.9	4.7	4.5	4.3	4.2	4.1	4.0	3.9	3.8	3.7
3.2	5.0	4.8	4.6	4.4	4.3	4.2	4.1	4.0	3.9	3.8
3.3	5.1	4.9	4.7	4.6	4.4	4.3	4.2	4.1	4.0	3.9
3.4	5.2	5.0	4.8	4.7	4.5	4.4	4.3	4.2	4.1	4.0
3.5	5.4	5.1	4.9	4.8	4.6	4.5	4.4	4.3	4.2	4.1
3.6	5.5	5.2	5.0	4.9	4.8	4.6	4.5	4.4	4.3	4.2
3.7	5.6	5.3	5.2	5.0	4.9	4.8	4.6	4.5	4.4	4.3
3.8	5.7	5.4	5.3	5.1	5.0	4.9	4.7	4.6	4.5	4.4
3.9	5.8	5.6	5.4	5.2	5.1	5.0	4.8	4.7	4.6	4.5
4.0	6.0	5.7	5.5	5.4	5.2	5.1	4.9	4.8	4.7	4.6
4.1	6.1	5.8	5.6	5.5	5.3	5.2	5.0	4.9	4.8	4.7
4.2	6.2	6.0	5.8	5.6	5.4	5.3	5.2	5.1	5.0	4.9
4.3	6.3	6.1	5.9	5.7	5.6	5.4	5.3	5.2	5.1	5.0
4.4	6.4	6.2	6.0	5.9	5.7	5.5	5.4	5.3	5.2	5.1
4.5	6.6	6.4	6.2	6.0	5.8	5.6	5.5	5.4	5.3	5.2

Height Of Dominants And Codominants

Future average heights of dominant and codominant lodgepole pines can be estimated if site index and stand age are known (table 3). In addition, the stands must never have been so dense that height growth was reduced. Heights at age 100 and site index class midpoints are not equal in table 3 because site indexes were obtained from the heights of dominant trees only.[7]

Stand Volume Equation

Stand volumes in cubic feet per acre can be determined from stand basal area and average height. The relationship is as follows:

$V = 16.96 + 0.50\ BH$ (Equation 3)

$r^2 = 0.998\ \ S_{y.x} = 44.85$ (2.3% of mean)

where:

V = gross volume per acre in cubic feet, from ground line to tip, of all trees larger than 4.5 feet tall,[8]

B = basal area per acre, in square feet,

H = average total height of dominant and codominant trees, in feet.

The equation is applicable to even-aged stands of lodgepole pine.

[8] *Myers, Clifford A. Volume tables and point-sampling factors for lodgepole pine in Colorado and Wyoming. U.S. Forest Serv. Res. Paper RM-6, 16 p. Rocky Mountain Forest and Range Exp. Sta., Ft. Collins, Colo. 1964.*

Table 3.--Average height of dominant and codominant trees at various ages, lodgepole pine in Colorado and Wyoming.

Main stand age (Years)	Site index class					
	30	40	50	60	70	80
10	5	6	6	7	7	8
20	10	12	14	17	19	22
30	14	17	21	25	28	32
40	16	20	25	31	35	40
50	18	23	29	36	41	47
60	20	26	33	41	47	54
70	22	29	37	45	52	60
80	24	32	41	49	57	66
90	26	34	44	53	62	71
100	28	37	47	57	66	76
110	30	39	49	60	69	80
120	32	41	52	63	72	83
130	33	43	54	65	75	86
140	35	45	56	67	77	88
150	37	47	58	69	79	90

Volume Conversion Factors

Volumes in total cubic feet of stem wood provide reliable measures of volume that do not change as utilization standards vary. Total volumes should, however, be convertible to other units so forest production can be estimated in terms familiar to the forest industry. Volumes computed from the stand volume equation can be converted to cubic feet to a 4-inch top (table 4a) or to board feet (table 4b). Multiply total cubic feet by the factor appropriate for the desired unit and the average stand diameter. Measurement standards such as stump height and merchantable top diameter are the same as for the tree volume equations from which the stand volumes used to obtain the factors were computed. [9]

Derivation of Yield Tables

Two sets of yield tables were prepared to illustrate the procedure for derivation of managed-stand yield tables. Five tables (tables 5 to 9) are based on a cutting interval of 10 years. Tables 10 to 14 show the results obtainable from cutting at 30-year intervals. Site indexes of 40 to 80 (base age 100 years) and stocking levels of 80 and 100 were selected for the examples because they are applicable to many stands in Colorado and Wyoming.

Procedure for the derivation of yield tables with 10-year cutting intervals is as follows:

1. Record number of trees and average stand diameter just prior to thinning for each site index class of interest. Compute basal area per acre from these two values. For example, the first set of entries for stand age 30 in table 5 describes stands ready for initial thinning.
2. Determine average diameter immediately after initial thinning from table 2 and the procedure described in the section "Diameter Increase from Thinning."
3. Obtain basal area immediately after initial thinning from the appropriate column of table 1 and the diameter determined in step 2. Divide this basal area by the basal area of the tree of average diameter to compute the number of trees present immediately after initial thinning.
4. Estimate average stand diameter in 10 years with equation 1. For example, 4.0 inches will increase to 4.9 inches in 10

[9] *See footnote 8, p. 5.*

Table 4a.--Factors for conversion of stand volumes in total cubic feet to merchantable cubic feet per acre. Lodgepole pine in Colorado and Wyoming[1/]

Average stand diameter (inches)	Ratio of merchantable to total volume	Average stand diameter (inches)	Ratio of merchantable to total volume
5.8	.494	10.4	.931
6.0	.547	10.6	.934
6.2	.599	10.8	.936
6.4	.651	11.0	.937
6.6	.690	11.5	.941
6.8	.724	12.0	.945
7.0	.753	12.5	.948
7.2	.778	13.0	.950
7.4	.800	13.5	.952
7.6	.819	14.0	.953
7.8	.835	14.5	.954
8.0	.849	15.0	.955
8.2	.861	15.5	.956
8.4	.871	16.0	.957
8.6	.880	16.5	.958
8.8	.888	17.0	.959
9.0	.896	17.5	.960
9.2	.902	18.0	.961
9.4	.908	18.5	.962
9.6	.914	19.0	.963
9.8	.919	19.5	.964
10.0	.924	20.0	.965
10.2	.928	20.5	.966

1/ To 4.0-inch top in trees 6.0 inches d.b.h. and larger.

Table 4b.--Factors for conversion of stand volumes in total cubic feet to board feet per acre[1/]

Average stand diameter (inches)	Ratio of board feet Scribner to total volume	Ratio of board feet Inter. ¼" to total volume
9.6	2.05	2.42
9.8	2.23	2.62
10.0	2.40	2.81
10.2	2.57	3.00
10.4	2.72	3.18
10.6	2.86	3.35
10.8	3.00	3.50
11.0	3.13	3.65
11.2	3.24	3.79
11.4	3.36	3.92
11.6	3.45	4.04
11.8	3.54	4.16
12.0	3.63	4.26
12.2	3.71	4.36
12.4	3.78	4.46
12.6	3.85	4.55
12.8	3.92	4.64
13.0	3.98	4.72
13.5	4.11	4.88
14.0	4.22	5.01
14.5	4.32	5.12
15.0	4.41	5.20
15.5	4.48	5.26
16.0	4.55	5.32
16.5	4.61	5.37
17.0	4.67	5.41
17.5	4.72	5.45
18.0	4.77	5.48
18.5	4.82	5.51
19.0	4.86	5.54
19.5	4.90	5.57
20.0	4.94	5.60
20.5	4.97	5.62

1/ In trees 10.0 inches d.b.h. and larger to an 8-inch top.

years under the conditions given in table 5.

5. Reduce number of trees present immediately after initial thinning by the amount of periodic loss. Percentage loss is determined from stand diameter, as follows:

Average stand diameter (Inches)	Trees lost in 10 years (Percent)
3.0 - 3.9	1.4
4.0 - 4.9	0.9
5.0 - 5.9	0.7
6.0 - 6.9	0.6
7.0 - 7.9	0.4
8.0 - 8.9	0.2
9.0+	0.0

For example, 403 trees at age 30 will be reduced to 399 trees at age 40 if average diameter is 4.0 inches at age 30.

6. Multiply number of trees (step 5) by the basal area of the tree of computed average diameter (step 4) to obtain basal area per acre 10 years after initial thinning. Retain one or two decimal places until the yield table is completed and checked.
7. Increase average diameter 0.3 inch to convert diameter before the second thinning to diameter after thinning. See the section "Diameter Increase from Thinning."
8. Obtain from table 1 the basal area after second thinning. Enter the table with the diameter after thinning of step 7 and the growing stock level already decided upon.
9. Divide basal area after second thinning (step 8) by the basal area of the tree of average diameter after second thinning (step 7) to obtain number of trees per acre.
10. Repeat steps 4 to 9 until the desired stand age is reached.
11. Compute the periodic changes in basal area with equation 2. Do not enter the results in the yield table, but compare them with yield table values. Basal areas from the equation and basal areas entered in the yield table will agree within ± 3.5 square feet if the projections of steps 4 to 10 are reasonable.
12. Record heights in the average height column of the yield table. Copy average dominant and codominant heights from the appropriate column of table 3.
13. Compute total cubic feet per acre before and after thinning for each stand age in the yield table. Use the stand volume equation, (equation 3). Do not round off volumes as shown in table 5 until the yield table is completed and checked.
14. Convert total cubic feet to other units per acre with the factors of tables 4a and 4b. Footnotes to these tables indicate the portion of the stand measured. The first entry of merchantable or board-foot volume in a yield table may occasionally show volume after thinning to be slightly larger than volume before thinning. In such cases, use the computed volume after thinning for both entries.
15. Round off basal area and volume values to remove unnecessary units and decimals that were retained during computations and checking.
16. Subtract values after thinning from values before thinning to obtain the periodic cuts. Volumes and basal areas of trees that died during the rotation could be computed and added to rotation totals, if desired. The amounts should be so small in managed stands that this computation would be unnecessary.

Yield tables with cutting cycles other than 10 years (tables 10 to 14) are derived with almost the same procedure as that outlined above. Differences are as follows:

1. Stand diameter, basal area, and number of trees are computed for each 10-year period. Computed values are then used in projections for the following 10 years with no changes due to thinning until the proper stand ages for cutting are reached.
2. Rethinning to the assigned stocking level will increase average stand diameter 0.4 inch with a 20-year cutting cycle and 0.5 inch with a 30-year cutting cycle.

After the yield tables have been compiled and checked, they are suitable for a variety of uses. Rotations may be determined from culmination of mean annual increment, with the effect of thinnings included in the computation. Rotations may be determined from the soil rent formula, with the yield tables providing data from which to compute money yields and costs of precommercial thinning. Site index classes may be converted to a productivity

classification based on a value such as maximum mean annual increment.

For all these purposes and many others, the yield table procedure given here provides: (1) information now instead of after many years' work on permanent plots, (2) a choice of alternatives for important management controls such as growing stock level, and (3) a means for quickly recomputing management guides if stocking goals or product objectives change.

Table 5.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 40, 10-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	6								
30	1,650	76	2.9	17	660							
30	403	35	4.0	17	320			1,247	41	340	0	0
40	399	52	4.9	20	540							
40	331	49	5.2	20	500			68	3	40	0	0
50	329	65	6.0	23	760	440						
50	274	59	6.3	23	700	440		55	6	60	0	0
60	272	73	7.0	26	960	720						
60	233	68	7.3	26	900	710		39	5	60	10	0
70	232	79	7.9	29	1,160	980						
70	201	74	8.2	29	1,090	940		31	5	70	40	0
80	201	85	8.8	32	1,380	1,220						
80	172	78	9.1	32	1,260	1,140		29	7	120	80	0
90	172	88	9.7	34	1,520	1,390	3,300					
90	147	80	10.0	34	1,380	1,270	3,300	25	8	140	120	0
100	147	90	10.6	37	1,680	1,570	4,800					
100	123	80	10.9	37	1,500	1,400	4,600	24	10	180	170	200
110	123	89	11.5	39	1,750	1,640	5,900					
110	105	80	11.8	39	1,580	1,490	5,600	18	9	170	150	300
120	105	88	12.4	41	1,820	1,730	6,900	105	88	1,820	1,730	6,900

Table 6.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 50, 10-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	6								
30	1,650	92	3.2	21	990							
30	377	40	4.4	21	430			1,273	52	560	0	0
40	374	59	5.4	25	760							
40	303	54	5.7	25	690			71	5	70	0	0
50	301	72	6.6	29	1,050	730						
50	249	65	6.9	29	960	700		52	7	90	30	0
60	248	80	7.7	33	1,340	1,110						
60	208	72	8.0	33	1,210	1,030		40	8	130	80	0
70	208	88	8.8	37	1,640	1,460						
70	172	78	9.1	37	1,460	1,310		36	10	180	150	0
80	172	92	9.9	41	1,900	1,750	4,400					
80	141	80	10.2	41	1,660	1,540	4,300	31	12	240	210	100
90	141	93	11.0	44	2,060	1,930	6,500					
90	115	80	11.3	44	1,780	1,670	5,900	26	13	280	260	600
100	115	92	12.1	47	2,170	2,060	8,000					
100	95	80	12.4	47	1,900	1,800	7,200	20	12	270	260	800
110	95	90	13.2	49	2,230	2,120	9,000					
110	80	80	13.5	49	1,980	1,880	8,100	15	10	250	240	900
120	80	89	14.3	52	2,340	2,230	10,000	80	89	2,340	2,230	10,000

Table 7.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 60, 10-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	7								
30	1,600	101	3.4	25	1,280							
30	366	42	4.6	25	540			1,234	59	740	0	0
40	363	64	5.7	31	1,010	490						
40	288	57	6.0	31	890	490		75	7	120	0	0
50	286	76	7.0	36	1,390	1,050						
50	233	68	7.3	36	1,240	970		53	8	150	80	0
60	232	85	8.2	41	1,760	1,520						
60	191	75	8.5	41	1,560	1,370		41	10	200	150	0
70	191	92	9.4	45	2,090	1,900	3,900					
70	155	79	9.7	45	1,810	1,650	3,900	36	13	280	250	0
80	155	95	10.6	49	2,340	2,190	6,700					
80	123	80	10.9	49	1,980	1,850	6,000	32	15	360	340	700
90	123	93	11.8	53	2,490	2,350	8,800					
90	100	80	12.1	53	2,140	2,020	7,800	23	13	350	330	1,000
100	100	94	13.1	57	2,680	2,550	10,800					
100	82	80	13.4	57	2,300	2,190	9,400	18	14	380	360	1,400
110	82	93	14.4	60	2,800	2,670	12,000					
110	68	80	14.7	60	2,420	2,310	10,500	14	13	380	360	1,500
120	68	91	15.7	63	2,900	2,770	13,100	68	91	2,900	2,770	13,100

Table 8.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 70, 10-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	7								
20	1,550	110	3.6	28	1,550							
30	458	53	4.6	28	760			1,092	57	790	0	0
40	454	83	5.8	35	1,470	730						
40	355	72	6.1	35	1,280	730		99	11	190	0	0
50	353	97	7.1	41	2,010	1,540						
50	286	86	7.4	41	1,770	1,420		67	11	240	120	0
60	285	110	8.4	47	2,590	2,260						
60	231	95	8.7	47	2,260	2,000		54	15	330	260	0
70	231	116	9.6	52	3,040	2,770	6,200					
70	187	100	9.9	52	2,610	2,410	6,100	44	16	430	360	100
80	187	119	10.8	57	3,410	3,190	10,200					
80	149	100	11.1	57	2,870	2,690	9,100	38	19	540	500	1,100
90	149	119	12.1	62	3,710	3,510	13,600					
90	119	100	12.4	62	3,120	2,950	11,800	30	19	590	560	1,800
100	119	117	13.4	66	3,860	3,680	15,800					
100	98	100	13.7	66	3,320	3,160	13,800	21	17	540	520	2,000
110	98	116	14.7	69	4,000	3,820	17,400					
110	81	100	15.0	69	3,470	3,310	15,300	17	16	530	510	2,100
120	81	115	16.1	72	4,140	3,960	18,900	81	115	4,140	3,960	18,900

Table 9.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 80, 10-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	8								
30	1,550	122	3.8	32	1,970							
30	436	57	4.9	32	930			1,114	65	1,040	0	0
40	432	91	6.2	40	1,830	1,100						
40	332	76	6.5	40	1,540	1,040		100	15	290	60	0
50	330	107	7.7	47	2,520	2,090						
50	260	91	8.0	47	2,150	1,820		70	16	370	270	0
60	259	117	9.1	54	3,180	2,850						
60	204	98	9.4	54	2,680	2,430		55	19	500	420	0
70	204	123	10.5	60	3,700	3,450	10,300					
70	157	100	10.8	60	3,020	2,820	9,100	47	23	680	630	1,200
80	157	121	11.9	66	4,020	3,790	14,400					
80	123	100	12.2	66	3,320	3,140	12,300	34	21	700	650	2,100
90	123	119	13.3	71	4,230	4,020	17,200					
90	99	100	13.6	71	3,570	3,400	14,700	24	19	660	620	2,500
100	99	118	14.8	76	4,510	4,310	19,700					
100	80	100	15.1	76	3,820	3,650	16,900	19	18	690	660	2,800
110	80	116	16.3	80	4,650	4,460	21,400					
110	67	100	16.6	80	4,020	3,850	18,600	13	16	630	610	2,800
120	67	116	17.8	83	4,820	4,630	22,900	67	116	4,820	4,630	22,900

Table 10.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 40, 30-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	6								
30	1,650	76	2.9	17	660							
30	403	35	4.0	17	320			1,247	41	340	0	0
60	392	82	6.2	26	1,090	650						
60	257	63	6.7	26	830	590		135	19	260	60	0
90	253	100	8.5	34	1,710	1,500						
90	175	78	9.0	34	1,330	1,200		78	22	380	300	0
120	175	107	10.6	41	2,220	2,070	6,300	175	107	2,220	2,070	6,300
							Totals:	1,635	189	3,200	2,430	6,300

Table 11.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 50, 30-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	6								
30	1,650	92	3.2	21	990							
30	377	40	4.4	21	430			1,273	52	560	0	0
60	369	96	6.9	33	1,600	1,180						
60	229	68	7.4	33	1,150	920		140	28	450	260	0
90	228	112	9.5	44	2,490	2,260	4,900					
90	147	80	10.0	44	1,780	1,640	4,300	81	32	710	620	600
120	147	117	12.1	52	3,070	2,900	11,300	147	117	3,070	2,900	11,300
							Totals:	1,641	229	4,790	3,780	11,900

Table 12.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 60, 30-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	7								
30	1,600	101	3.4	25	1,280							
30	366	42	4.6	25	540			1,234	59	740	0	0
60	358	107	7.4	41	2,210	1,770						
60	211	72	7.9	41	1,490	1,260		147	35	720	510	0
90	210	124	10.4	53	3,300	3,070	9,000					
90	123	80	10.9	53	2,140	2,000	6,500	87	44	1,160	1,070	2,500
120	123	122	13.5	63	3,870	3,680	15,900	123	122	3,870	3,680	15,900
							Totals:	1,591	260	6,490	5,260	18,400

Table 13.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 70, 30-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	7								
30	1,550	110	3.6	28	1,550							
30	458	53	4.6	28	760			1,092	57	790	0	0
60	448	137	7.5	47	3,250	2,630						
60	260	91	8.0	47	2,150	1,820		188	46	1,100	810	0
90	258	158	10.6	62	4,920	4,590	14,100					
90	149	100	11.1	62	3,120	2,920	9,900	109	58	1,800	1,670	4,200
120	149	155	13.8	72	5,590	5,330	23,400	149	155	5,590	5,330	23,400
							Totals:	1,538	316	9,280	7,810	27,600

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Table 14.--Yields per acre of managed, even-aged stands of lodgepole pine in Colorado and Wyoming.

Site index 80, 30-year cutting cycle.

Stand age (years)	Trees	Basal area	Ave. d.b.h.	Average height	Volume			Periodic cut				
					Total	Merch.	Sawtimber	Trees	Basal area	Total vol.	Merch. vol.	Sawtimber vol.
	No.	Sq.ft.	In.	Ft.	--Cu.ft.--		Bd.ft.	No.	Sq.ft.	--Cu.ft.--		Bd.ft.
10	2,000	4	0.6	8								
30	1,550	122	3.8	32	1,970							
30	436	57	4.9	32	930			1,114	65	1,040	0	0
60	427	157	8.2	54	4,240	3,650						
60	231	95	8.7	54	2,590	2,290		196	62	1,650	1,360	0
90	231	172	11.7	71	6,140	5,790	21,500					
90	123	100	12.2	71	3,570	3,370	13,200	108	72	2,570	2,420	8,300
120	123	159	15.4	83	6,620	6,330	29,600	123	159	6,620	6,330	29,600
							Totals:	1,541	358	11,880	10,110	37,900

Myers, Clifford A.
1967. Yield tables for managed stands of lodgepole pine in Colorado and Wyoming. U. S. Forest Serv. Res. Paper RM-26, 20 pp. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 80521.

Presents working tools useful in the compilation of yield tables for managed, even-aged stands. Stand age at initial thinning, stocking goals, and other management controls may be varied as desired. The yield table that best describes the objectives of management becomes the standard for the forest.

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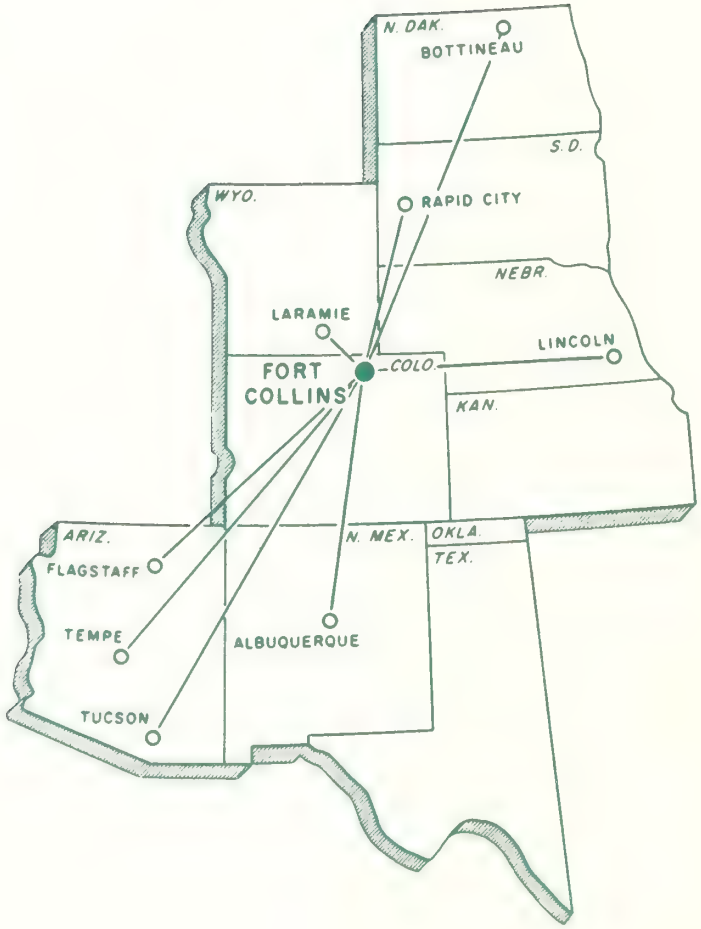
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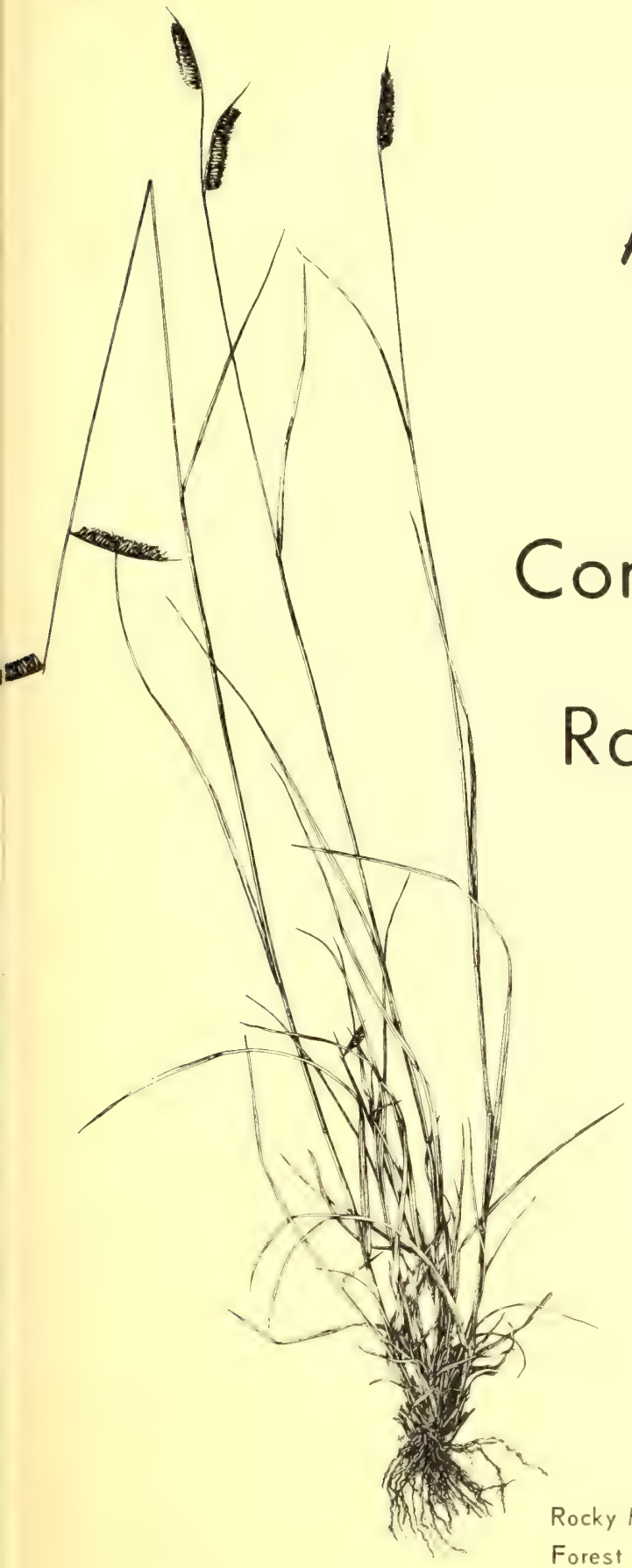

A Vegetative Key

to some

Common Arizona Range Grasses

R. F. Copple and C. P. Pase

Rocky Mountain Forest and Range Experiment Station
Forest Service U. S. Department of Agriculture

ABOUT THE COVER:

Hairy grama (Bouteloua hirsuta), a desirable forage grass characteristic of many southwestern ranges.

U. S. Forest Service Research Paper RM-27 1967

A VEGETATIVE KEY TO SOME COMMON ARIZONA RANGE GRASSES

by

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A Vegetative Key to Some Common Arizona Range Grasses

R. F. Copple and C. P. Pase

INTRODUCTION

Native and cultivated grasses must often be identified when plants are immature or have been heavily grazed and, thus, do not have flower stalks. Under such conditions, conventional botanical manuals offer little assistance. Examination of vegetative characteristics, however, will often permit tentative identification until better developed specimems are available.

The purpose of this paper is to present an illustrated key for the identification of 77 common Arizona range and pasture grasses by vegetative characters.

A technical knowledge of taxonomic botany, although useful, is not essential to use this method of identification. A common magnifying glass or hand lens of 5 to 10 power, plus a small millimeter scale, will prove helpful.

This publication is planned to be used in conjunction with Arizona Range Grasses (Ariz. Agr. Exp. Sta. Bull. 298),[3] or with Hitchcock's Manual of the Grasses of the United States (U.S. Dep. Agr. Misc. Pub. 200). Photographs or drawings of the plants covered here may be found in these two publications.

DESCRIPTIONS OF VEGETATIVE CHARACTERS

Annual or perennial.--Annual grasses generally have fine, poorly developed root systems, and no evidence of old, previous year's culm bases. Perennial grass root systems are better developed, and evidence of last year's leaves or flower stalks can usually be found. Presence of creeping root stalks, rhizomes, stolons, etc., always indicates a perennial grass. Seedling perennial grasses may occasionally be confused with annuals. Some caution should be used with this character in short-lived perennials such as Bouteloua rothrockii (plate I).

Vernation.--This refers to the cross section of a grass blade in a developing shoot. Vernation may be best determined by cutting across the sheath just below the collar, and observing the shape of the enclosed cut blade with a strong hand lens. Care should be used to make the cross section with a razor blade or sharp knife, to avoid mashing the enclosed blade and destroying its original shape. Vernation may be folded, rolled (or curled), or clasped (plate II).

Folded vernation is generally associated with a flattened sheath, and rolled or clasped with a rounded sheath, but this does not always hold true.

Blades.--Width and length of blades vary somewhat, depending on growing conditions, but within limits offer an easy method to separate certain species. Shaded plants have longer and wider blades than those exposed to the sun.

Nerves may be raised on either surface--sometimes prominently, as on the upper surface of Koeleria cristata blades.

Blades may be folded, flattened, or rounded. Normally flat blades may tend to appear round as they dry, but examination of the base of the blade above the sheath will reveal its normal condition. Blade tips may be boat-shaped, as in some species of Poa.

Grass blades are two-ranked, while sedges are three-ranked (plate I).

[3] *Publications used for reference in preparing this Vegetative Key are listed on p. 69.*

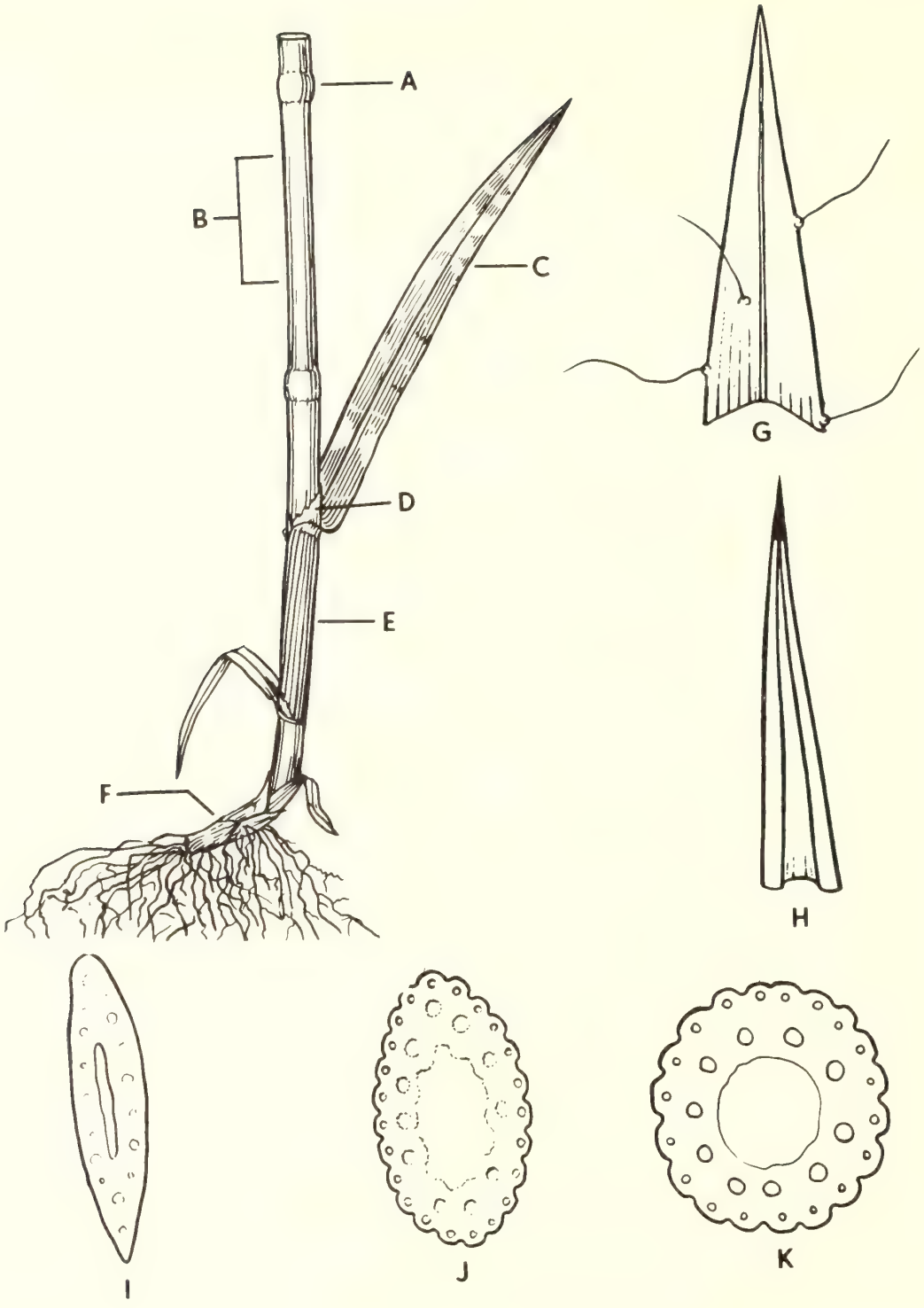


Plate I.--Grass identification characters.
Parts of typical grass plant: A, node; B, internode; C, blade; D, ligule; E, sheath; F, rhizome. Leaf blades: G, with glandular hairs; H, with pungent tip. Culm shape in cross section: I, flat; J, elliptical; K, round.

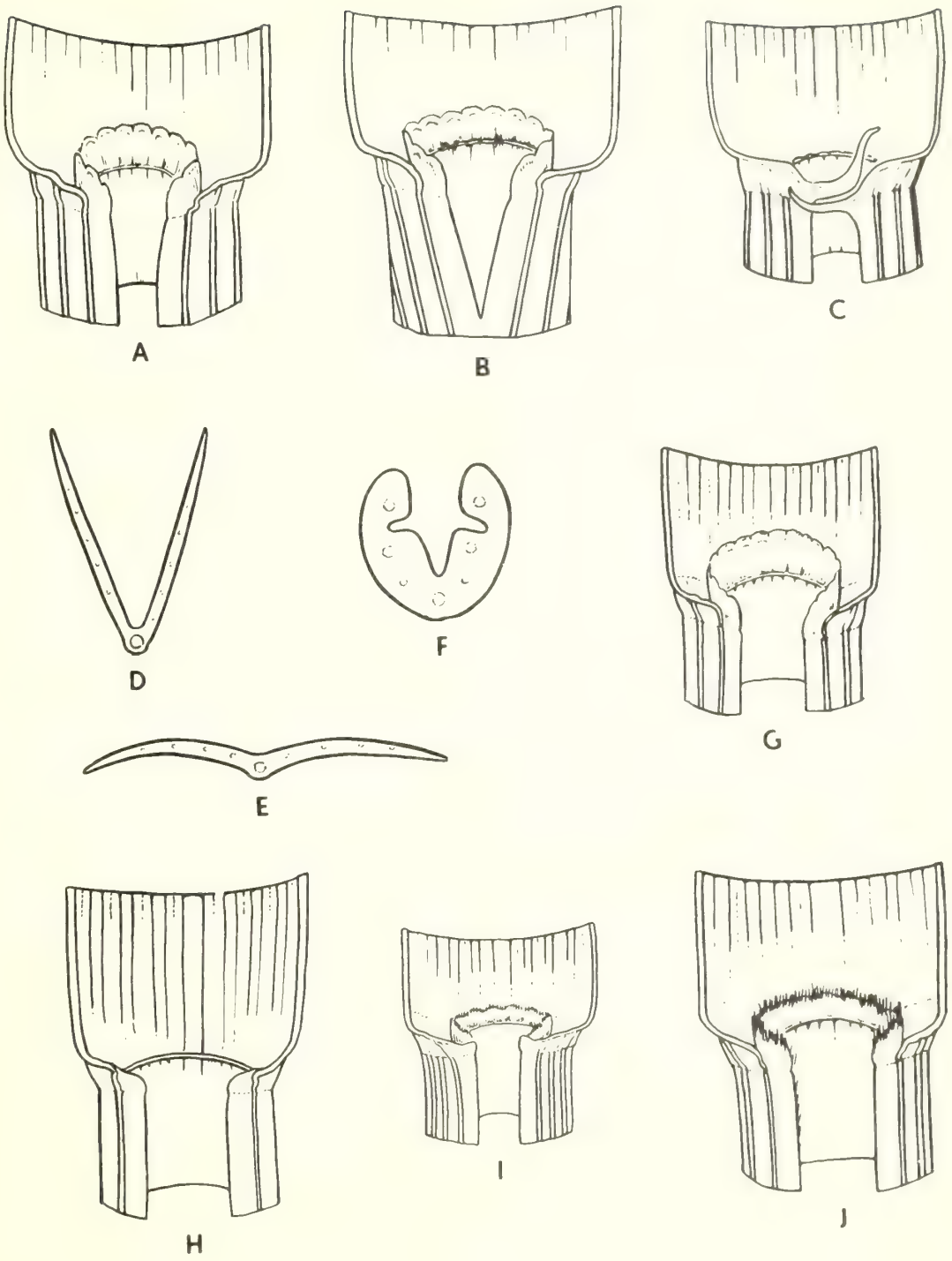


Plate II.--Grass identification characters.
Sheaths: A, open; B, closed; C, with clasping auricle. Leaf shape in cross section: D, folded; E, flat; F, round. Ligule types: G, membranous; H, collar-like; I, hairy; J, truncate-ciliate (membranous with ciliate margin).

Auricle.--Small, membranous extensions of the collar of some grasses, notably of Agropyron, Lolium, and others of the tribe Hordeae (plate II).

Ligule.--This is an organ clasping the stem at the junction of the blade and sheath. It may be membranous or hairy, or both, as in truncate-ciliate ligules. Size, shape, and type of ligule is quite constant, and provides one of the best vegetative characters for identification (plate III).

Collar.--This is the junction of leaf blade and sheath. It may be a broad or narrow band, glabrous or covered with fine hair. The margin may be glabrous, hairy, or with glandular hairs.

Sheath.--The tubular basal portion of the leaf, below the blade that clasps the stem. The sheath may be closed, as in Bromus, or open. Ruptured closed sheaths should not be confused with normally open ones (plate II).

The sheath of certain grasses may have a thin, membranaceous, hyaline margin.

Nodes.--The joints of a grass stem or culm.

Internodes.--The area between successive nodes.

Roots.--Grass root systems are fibrous, but rhizomes or thickened underground stems may also be present.

Culm.--The flowering stem of a grass, generally round or elliptical in cross section (plate I) as opposed to the triangular stems of sedges. Rushes have pithy stems, while most grasses have hollow stems.

Considerable variation may be expected in certain characters such as degree of hairiness of the blade or sheath, length and width of blade, etc. It may therefore be necessary to examine several specimens before deciding what is a representative condition. Other characteristics, such as type of ligule and vernation, are generally rather constant.

HOW TO USE THE KEY

To use the key, first examine the plant to see if it is annual or perennial. If perennial, go to Section B. Identification is then made by a series of opposing choices, until a name is reached in the key.

In the short-cut method, refer first to the condensed key which lists major characters with their number location in the key. For example, should the plant have stolons, go immediately to Item 10 in the key, and continue from there. Should this fail to bring you to an acceptable decision, start over at the beginning of the key. Remember, only 77 of the more common range grasses are covered by this key.

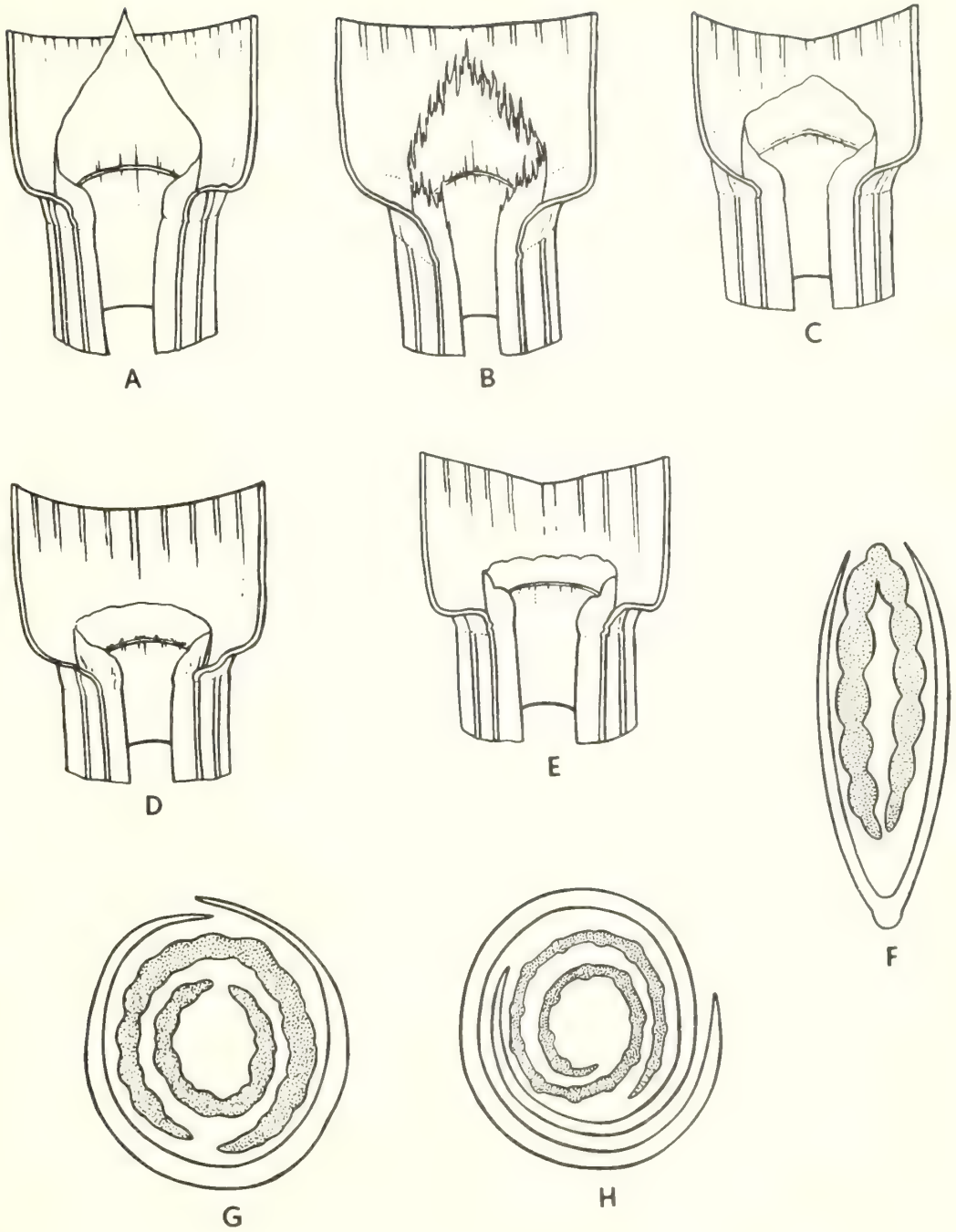


Plate III.--Grass identification characters.
Ligule shapes: A, [illegible]; B, [illegible]; C, [illegible]; D, [illegible]; E, truncate-notched. Vernation (cross section of leaf in bud): F, folded; G, clasped; H, curled or rolled.

CONDENSED KEY

Major Character Headings by Number in Key

Section A - Annual

Section B - Perennial

1- Auricle present

3- Blade glossy on lower surface

5- Bulb present

6- Flowers and blades clustered at apex

7- Blade tip very sharp

8- Ligule large, 5-18 mm.

10- Stolons present

14,77- Rhizomes present

23- Sheath margin white

23,25- Blade margin white

28- Letter M or W on blade

29- Rachis extends beyond florets

30- Culms root at nodes

33,80- Internode hairy or woolly

37- Blade margin with glandular hairs

42- Growth a mat or sod

44- Sheath closed partially or completely

46- Node hairy, pubescent, or woolly

74- Panicle included in sheath

GRASSES GROUPED ACCORDING TO OUTSTANDING CHARACTERS

1. **Auricles**
   - 1 - *Agropyron desertorum*
   - 2 - *Agropyron smithii*
   - 66 - *Sitanion hystrix*
   - 44 - *Lolium perenne*
2. **Stolons**
   - 31 - *Cynodon dactylon*
   - 32 - *Distichlis stricta*
   - 38 - *Hilaria belangeri*
   - 57 - *Panicum obtusum*
3. **Nodes Hairy or Pubescent**
   - 4 - *Andropogon barbinodis*
   - 38 - *Hilaria belangeri*
   - 41 - *Hilaria rigida*
   - 50 - *Muhlenbergia pungens*
   - 64 - *Setaria geniculata*
   - 75 - *Trichachne californica*
   - 76 - *Tridens muticus*
4. **Blade Tip Very Sharp**
   - 50 - *Muhlenbergia pungens*
5. **Flowers Clustered at Apex**
   - 77 - *Tridens pulchellus*
6. **Corm or Bulb**
   - 55 - *Panicum bulbosum*
7. **Sheath Margin White**
   - 45 - *Lycurus phleoides*
   - 51 - *Muhlenbergia richardsonis*
   - 62 - *Schedonnardus paniculatus*
8. **Stems or Culm Root at Nodes**
   - 19 - *Bouteloua eriopoda*
   - 38 - *Hilaria belangeri*
   - 77 - *Tridens pulchellus*
9. **Rachis Extends Beyond Spikelets**
   - 22 - *Bouteloua hirsuta*
10. **Sheath Closed Partially or Completely**
   - 24 - *Bromus anomalus*
   - 25 - *Bromus arizonicus*
   - 26 - *Bromus ciliatus*
   - 27 - *Bromus inermis*
   - 28 - *Bromus rubens*
   - 29 - *Bromus tectorum*
11. **Flowers Inserted in Sheath**
   - 69 - *Sporobolus asper*
   - 70 - *Sporobolus cryptandrus*
12. **Internode Hairy**
   - 19 - *Bouteloua eriopoda*
   - 33 - *Elyonurus barbiculmis*
   - 41 - *Hilaria rigida*
   - 64 - *Setaria geniculata*
13. **Blade Margin with Glandular Hairs**
   - 15 - *Bouteloua aristidoides*
   - 17 - *Bouteloua chondrosioides*
   - 18 - *Bouteloua curtipendula*
   - 19 - *Bouteloua eriopoda*
   - 20 - *Bouteloua filiformis*
   - 22 - *Bouteloua hirsuta*
   - 23 - *Bouteloua rothrockii*
   - 37 - *Heteropogon contortus*
   - 38 - *Hilaria belangeri*
   - 56 - *Panicum bulbosum*

70 - *Sporobolus cryptandrus*

75 - *Trichachne californica*

77 - *Tridens pulchellus*

27. **Ligule Large - Acute**

A - 2-5 mm.

25 - *Bromus arizonicus*

34 - *Eragrostis intermedia*

45 - *Lycurus phleoides*

59 - *Poa longiligula*

B - 5-8 mm.

48 - *Muhlenbergia montana*

C - 8-15 mm.

47 - *Muhlenbergia emersleyi*

VEGETATIVE KEY

Section A — Plants, Annual

1a Ligule a membrane or collar (a truncate-ciliate ligule is classified as membranous).

2a Sheath closed.

3a Blades 4-6 mm. wide ..... 25. *Bromus arizonicus*

3b Blades narrower, 1-4 mm. wide.

4a Ligule acute-lacerate; internodes sometimes puberulent near nodes; mature plants reddish brown. Lower chaparral and desert shrub formations below 6,000 feet ..... 28. *Bromus rubens*

4b Ligule obtuse-lacerate; internodes glabrous. Generally above 6,000 feet ..... 29. *Bromus tectorum*

2b Sheath open.

5a Ligule truncate-ciliate, 1 mm.; blades with dorsal glandular hairs; lower nodes geniculate; culms branched; awned. Below 5,000 feet ..... 30. *Chloris virgata*

5b Ligule acute-lacerate, 2-4 mm. long; blades 2-5 mm. wide 4-12 cm. long. Desert to woodland 1,000-5,000 feet. ..... 58. *Poa bigelovii*

1b Ligule hairy.

6a Blades needle-like, short and decumbent, 1/2-1 mm. wide, 3-8 cm. long; long hairs back of ligule and collar, 3-8 mm. long. Dry slopes and sandy washes below 4,000 feet. ..... 63. *Schismus barbatus*

6b Blade not needle-like.

7a Collar and blade with glandular hairs, 2-3 mm.; blade in bud folded, 1/2 mm. wide, 1-2 cm. long; ligule hairy, 1/2 mm.; awns 1-2 cm. Below 6,000 feet. ..... 7. *Aristida adscensionis*

7b Collar without glandular hairs.

8a Blade margin with glandular hairs; culm elliptical; ligule hairy, 1/2 mm., blade in bud curled; stem branches; blades 1/2 mm. wide, 2-7 cm. long. Woodland below 6,000 feet. ..... 15. *Bouteloua aristidoides*

8b Blade margin without glandular hairs, flat, narrow and short, 1 mm. wide, 2-4 cm. long; culm round, ligule hairy, 1 mm.; awns, 1-2 mm. Waste places throughout the State below 6,000 feet ..... 16. *Bouteloua barbata*

1a Auricle present, sometimes rudimentary.

2a Auricle prominent, clawed.

3a Blades glossy below; introduced plants of lawns, tame pastures ..... 44. *Lolium perenne*

3b Blades not glossy below.

4a Rhizomes present; blade ribs prominent dorsally; foliage characteristically glaucous, blue-green. ..... 2. *Agropyron smithii*

4b Rhizomes absent; blades conspicuously pubescent or rarely glabrous; tufted bunchgrass ..... 66. *Sitanion hystrix*

2b Auricle rudimentary ..... 1. *Agropyron desertorum*

1b Auricle absent.

5a Culm-bases thickened into bulb-like corms. ..... 55. *Panicum bulbosum*

5b Culm-bases not bulb-like.

6a Inflorescences and blades clustered at the apex, the blades exceeding the uppermost florets; plants small, blades involute, 2-5 cm. long, 1/4 mm. wide, the plant 5-10 cm. high. ..... 77. *Tridens pulchellus*

6b Inflorescences and blades not clustered at apex.

7a Blade tip pungent, stiff and sharp; common on loose sand, woodland and pine areas ..... 50. *Muhlenbergia pungens*

7b Blade tips not sharp.

8a Ligule large, 5-18 mm.

9a Ligule acute-lacerate; culm elliptical; blades folded; large coarse bunchgrass ..... 47. *Muhlenbergia emersleyi*

9b Ligule acute-entire; culm round; blades rolled, occasionally flat; small bunchgrass ..... 48. *Muhlenbergia montana*

8b Ligule smaller, usually 1/2-3 mm.

10a Stolons present.

11a Sheaths pubescent or hirsute.

12a Sheaths with glandular hairs ..... 56. *Panicum obtusum*

12b Sheaths without glandular hairs ... 31. *Cynodon dactylon*

11b Sheaths glabrous

13a Internodes woolly ..... 19. *Bouteloua eriopoda*

13b Internodes glabrous ..... 38. *Hilaria belangeri*

10b Stolons absent.

14a Rhizomes present.

15a Sheath closed, letter M or W on blade.

..... 27. *Bromus inermis*

15b Sheath open.

16a Ligule of hairs.

17a Blades large, 10-12 mm. wide, 20-40 cm. long; ligule 1-2 mm.; rhizomes massive, often flattened; fields, ditchbanks, roadsides.

..... 67. *Sorghum halepense*

17b Blades smaller, 2-3 mm. wide, 1-6 cm. long, frequently with salt deposits on upper surface.

..... 32. *Distichlis stricta*

16b Ligule membranous.

18a Blade folded, the tip boat-shaped; ligule truncate-entire ..... 61. *Poa pratensis*

18b Blade not folded.

19a Plant woolly, the bases coarse, semiwoody; dry areas below 4,000 feet ..... 41. *Hilaria rigida*

19b Plants not woolly.

20a Blades rolled, growth mat-like.

..... 51. *Muhlenbergia richardsonis*

20b Blades not rolled, growth not mat-like.

21a Ligule truncate-ciliate, 1-2 mm.; blades 2-4 mm. wide, 5-10 cm. long, curled in the bud; culms branch at the nodes; dry, tight-soil flats, 2,000-6,000 feet, central and southern Arizona.

..... 40. *Hilaria mutica*

21b Ligule not truncate-ciliate.

22a Ligule truncate-lacerate, 1-2 mm.; blade curled in the bud, involute, the base of blade usually flat, 2-5 mm. wide, 4-12 cm. long; dry flats on tight soils, central and northern Arizona, 4,500-7,000 feet..... 39. *Hilaria jamesii*

22b Ligule obtuse-entire, 1-2 mm.; blades 2-5 mm. wide, 3-8 cm. long; wet, cool sites generally along streams, 5,000-9,000 feet.

..... 3. *Agrostis alba*

14b Rhizomes absent.

23a Both sheath and blade margin white.

24a Blade folded, ligule acute-entire, 2-5 mm.; culms branched; small bunchgrass of dry woodland and pine, 4,000-7,000 feet ..... 45. *Lycurus phleoides*

24b Blade needle-like, ligule truncate-toothed, growth mat-like ..... 51. *Muhlenbergia richardsonis*

23b Both sheath and blade margins not white.

25a Blade margins white.

26a Ligule hairy ..... 67. *Sorghum halepense*

26b Ligule not hairy but membranous.

27a Nodes woolly; ligule a collar, obtuse-lacerate 2-3 mm.; hairs on back of ligule 3-5 mm.; medium to large bunchgrass; dry, rocky slopes 1,000-6,000 feet ..... 4. *Andropogon barbinodis*

27b Nodes hairy but scarcely woolly, the culms erect from a knotty swollen felty-pubescent base, 40-100 cm. tall; sheaths glabrous to sparsely pilose; blades 3-5 mm. wide, 8-12 cm. long ..... 75. *Trichachne californica*

25b Blade margins not white.

28a Blades with letters M or W ..... 27. *Bromus inermis*

28b Blades not as above.

29a Rachis extends beyond florets. ..... 22. *Bouteloua hirsuta*

29b Rachis does not extend beyond florets.

30a Culms root at nodes.

31a Blades with glandular hairs on upper side.

..... 38. *Hilaria belangeri*

31b Blades without glandular hairs on upper side.

32a Internodes woolly ..... 19. *Bouteloua eriopoda*

32b Internodes not woolly, the ligule ciliate.

..... 77. *Tridens pulchellus*

30b Culms not rooting at nodes.

33a Internodes hairy or woolly, the ligules hairy.

34a Ligule 1/2 mm. ..... 19. *Bouteloua eriopoda*

34b Ligule larger, 1-2 mm.

35a Blade rolled, 1 mm. wide, 15-30 cm. long.

..... 33. *Elyonurus barbiculmis*

35b Blade not rolled, wider.

36a Blade flat, node woolly; ligule obtuse-lacerate 2-3 mm.

..... 4. *Andropogon barbinodis*

36b Blade folded; ligule, node and lower internode hairy.

..... 64. *Setaria geniculata*

(see continuation)

(continuation)

33b Internodes not hairy nor woolly.

37a Blade margins, at least at the base, with glandular hairs.

38a Ligule membranous, 1-2 mm., collar with glandular hairs.

..... 18. *Bouteloua curtipendula*

38b Ligule not membranous.

39a Culm flattened ..... 37. *Heteropogon contortus*

39b Culm round in corss section.

40a Ligule 2-4 mm. ..... 23. *Bouteloua rothrockii*

40b Ligule smaller.

41a Blade in bud clasped ... 17. *Bouteloua chondrosioides*

41b Blade in bud curled ..... 20. *Bouteloua filiformis*

37b Blade margins without glandular hairs.

42a Growth a sod or mat-like.

43a Ligule hairy ..... 21. *Bouteloua gracilis*

43b Ligule membranous ..... 53. *Muhlenbergia torreyi*

42b Growth not a sod or mat-like.

44a Sheaths closed.

45a Ligule truncate-notched; culm round.

..... 26. *Bromus ciliatus*

45b Ligule truncate-toothed, culm elliptical.

..... 24. *Bromus anomalus*

44b Sheaths open.

46a Nodes woolly or pubescent.

47a Ligule obtuse-lacerate ..... 4. *Andropogon barbinodis*

47b Ligule not obtuse-lacerate.

48a Blades folded ..... 64. *Setaria geniculata*

48b Blades not folded.

49a Blades flat ..... 41. *Hilaria rigida*

49b Blades round.

50a Blade small, about 1 mm. wide, 2-5 cm. long; ligule truncate-ciliate; blade tip very sharp to the touch; sandy soils of woodland and pine. ..... 50. *Muhlenbergia pungens*

50b Blades larger, 2-4 mm. wide, 8-20 cm. long; sheath margin hairy; blade in bud curled; blade usually rolled; ligule small, hairy; desert grassland and oak woodland below 5,500 feet ..... 76. *Tridens muticus*

46b Nodes not woolly or pubescent.

51a Blades folded.

52a Growth a mat, ring-like .....53. *Muhlenbergia torreyi*

52b Growth not mat-like or ring-like.

53a Ligule large, 8-15 mm. ..47. *Muhlenbergia emersleyi*

53b Ligule smaller.

54a Culm branched ..... 45. *Lycurus phleoides*

54b Culm not branched.

55a Ligule shorter than 1 mm.

56a Ligule obtuse-lacerate.

..... 6. *Andropogon scoparius*

56b Ligule not obtuse-lacerate.

57a Ligule obtuse-toothed, about 1/2 mm.; blades long, narrow, folded; woodlands and pine forests, 5,000-11,500 feet, rarely down to 3,500 feet.

..... 59. *Poa fendleriana*

57b Ligule truncate-entire, 1/4-1/2 mm.; bunch or sodgrass; common in moist meadows at medium and high elevations throughout the State ..... 61. *Poa pratensis*

55b Ligule longer than 1 mm.

58a Ligule obtuse-entire, 1-2 mm.; old growth usually flat, new growth blades folded, long, narrow, plant commonly has a reddish cast; woodland and pine forest fringe, 2,000-7,500 feet ..... 5. *Andropogon cirratus*

58b Ligule not obtuse-entire.

59a Ligule acute-lacerate, 2-4 mm.; blade 1 mm. wide, 10-20 cm. long, common in chaparral, 3,500-7,500 feet ..... 60. *Poa longiligula*

59b Ligule acute-entire, 2-3 mm.; blade margin white; woodland and pine, often on disturbed sites.

..... 62. *Schedonnardus paniculatus*

51b Blade not folded.

60a Blades round, needle-like.

61a Ligule a collar or membranous.

62a Ligule large, 5-8 mm., acute-entire; blade in bud folded, a small bunchgrass, common in woodland and pine forests; 4,500-9,500 feet. ..... 48. *Muhlenbergia montana*

62b Ligule smaller.

63a Ligule less than 1 mm. long.

64a Ligule truncate-ciliate.

65a Ligule with hairs on back, 1-2 mm.; blade in bud curled; short rhizomes often present; large coarse bunchgrass of alkali flats; 2,500-6,500 feet ..... 68. *Sporobolus airoides*

65b Ligule with no hairs on back, truncate-ciliate, 1/4-1/2 mm.; blade clasped in the bud; culms occasionally branched at nodes; small bunchgrass of dry upland sites; 3,500-6,000 feet. ..... 10. *Aristida glauca*

64b Ligule not truncate-ciliate.

66a Ligule obtuse-ciliate, 1/4 mm.; blade 1/2 mm. wide, 25-35 cm. long, needle-like, awns long, twisted, with long hairs extending to the tip. ..... 73. *Stipa neomexicana*

66b Ligule not obtuse-ciliate.

67a Ligule truncate-entire, 1/4 mm.; blade 1 mm. wide, 5-10 cm. long; small bunchgrass of pine forests, 6,000-10,000 feet, occasionally lower ..... 14. *Blepharoneuron tricholepis*

67b Ligule acute-entire, very small, 1/4-1/2 mm.; blade 1/2-1 mm. wide, 10-30 cm. long; large bunchgrass of forest, parks and dry meadows, 7,000-10,000 feet.

..... 36. *Festuca arizonica*

63b Ligule longer than 1 mm.

68a Ligule lacerate.

69a Blade veins each side of midvein 2; blade in bud clasped; sheath margin white; large coarse bunchgrass, commonly on moist, rocky sites along intermittent streams; 3,000-7,000 feet.

..... 52. *Muhlenbergia rigens*

69b Blade veins each side of midvein 3-4; juniper and pine, 6,500-8,000 feet.

..... 46. *Muhlenbergia curtifolia*

68b Ligule entire, 2-3 mm.; collar margin pubescent; blade 1/2 mm. wide, 5-20 cm. long; common in juniper-pinyon, 3,500-6,500 feet.

..... 54. *Oryzopsis hymenoides*

61b Ligule of hairs.

70a Blade in bud clasped.

71a Ligule and collar bearded; dry sites; woodland to pine, 4,000-7,000 feet.

..... 8. *Aristida divaricata*

71b Ligule not bearded.

72a Awns 2-4 cm. long; culms branch freely; blade hairs on upper surface 2-3 mm.

..... 9. *Aristida glabrata*

72b Awns 5-8 cm. long; culms unbranched; blades glabrous on upper surface.

..... 11. *Aristida longiseta*

70b Blade in bud folded.

73a Collar bearded; blades 1/2 mm. wide, 2-8 cm. long; awns 2-4 mm., with purplish cast; blades rolled, needle-like, desert to pine, 1,000-7,000 feet ..... 12. *Aristida purpurea*

73b Collar not bearded, awns 1 long, 2 short; culm unbranched; collar with hairy margin only; culms elliptical; dry uplands; 2,500-5,500 feet.

..... 13. *Aristida ternipes*

60b Blades flat, not round or needle-like.

74a Panicle exserted, not included in the sheath.

75a Ligule of hairs for half or more its length.

76a Blades sparsely pilose to pubescent, at least below.

77a Plants with rhizomes, forming an open to dense sod; blades narrow.

78a Blades rolled; salt crystals often on blades; lower culms and rhizomes conspicuously shiny. ..... 32. *Distichlis stricta*

78b Blades flat, the older ones often curled; salt deposits wanting; culms and rhizomes not as above ..... 21. *Bouteloua gracilis*

77b Plants without rhizomes; blades 4-5 mm. wide. ..... 43. *Leptochloa dubia*

76b Blades glabrous.

79a Sheaths pubescent on the margin or summit.

80a Nodes and internodes glabrous; collar margins distinctly tufted; culms round. ..... 71. *Sporobolus giganteus*

80b Nodes and internodes sparsely hairy; collar margin not tufted; culms flat. ..... 65. *Setaria macrostachya*

79b Sheaths glabrous.

81a Culms branched, blades 12-15 cm. long. ..... 35. *Eragrostis lehmanniana*

81b Culms simple, blades 45-60 cm. long. ..... 72. *Sporobolus wrightii*

75b Ligule membranous, sometimes ciliate.

82a Leaf folded in the bud; veins prominent ventrally. Small bunchgrass ..... 42. *Koeleria cristata*

82b Leaf rolled in the bud.

83a Culms branched.

84a Sheaths and nodes pubescent. Introduced grass ..... 35. *Eragrostis lehmanniana*

84b Sheaths and nodes glabrous.

85a Wiry decumbent bunchgrass, often clambering over shrubs; blades 3-8 cm. long. ..... 49. *Muhlenbergia porteri*

85b Erect bunchgrass, blades 15-30 cm. long. ..... 57. *Pappophorum mucronulatum*

83b Culms not branched.

86a Nodes pubescent; ligule obtuse-lacerate. ..... 74. *Stipa pringlei*

86b Nodes glabrous; ligule truncate-ciliate. ..... 34. *Eragrostis intermedia*

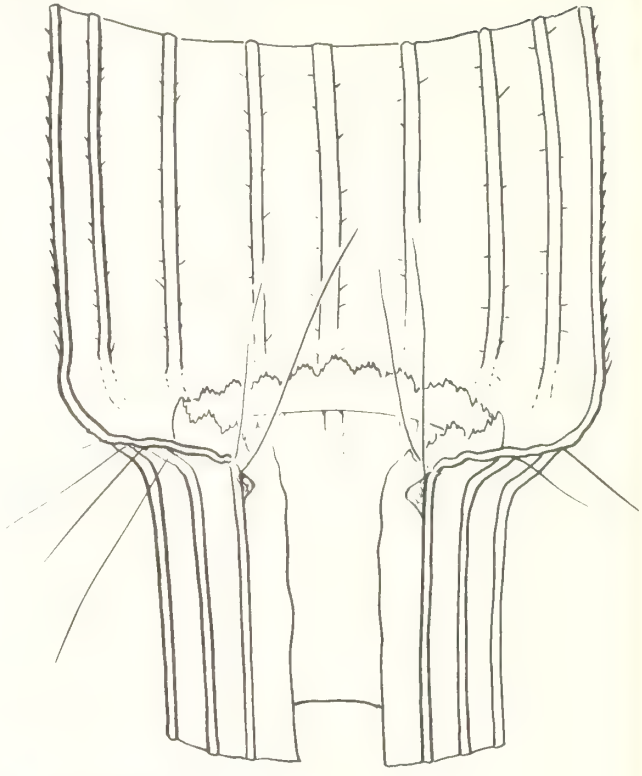
74b Panicle partly or wholly covered by the sheath.

87a Culm branched ..... 69. *Sporobolus asper*

87b Culms not branched .... 70. *Sporobolus cryptandrus*

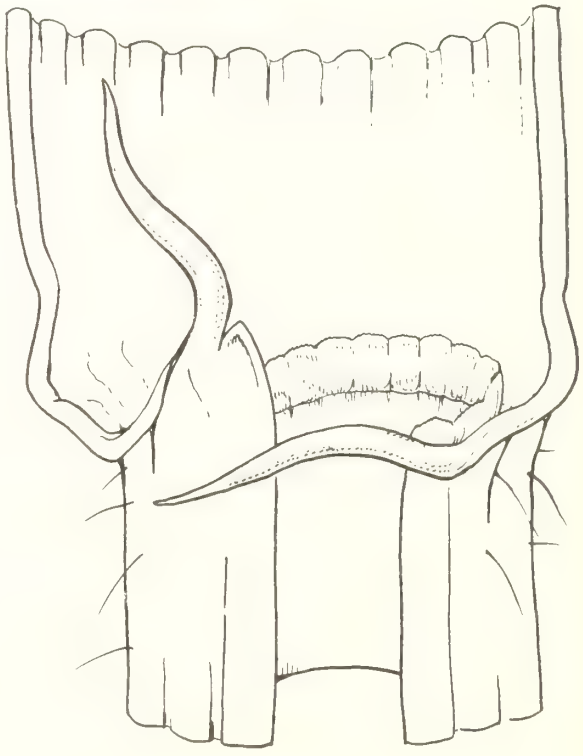
DESCRIPTIONS OF SPECIES

1. *Agropyron desertorum* (Fisch.) Schult. CRESTED WHEATGRASS



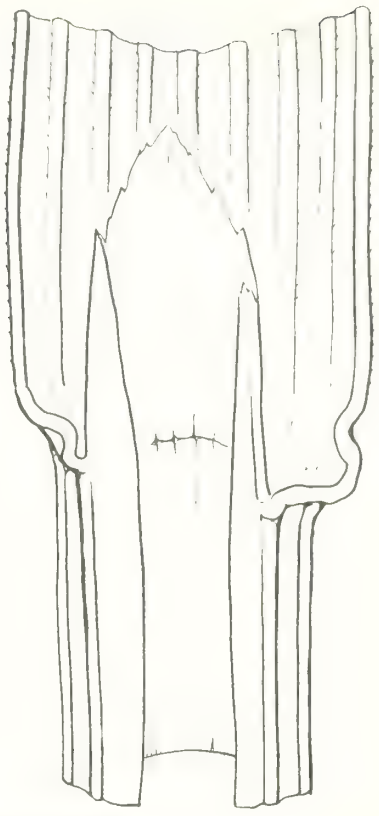
Erect, medium size bunchgrass. VERNATION - Curled. BLADES - Flat, 2-5 mm. wide, 8-20 cm. long; semi-erect; rough ventrally; veins each side of midrib usually three; ribs prominent dorsally, 12-18; blade margin toothed. AURICLE - Small, often rudimentary. LIGULE - Membranous, collar-like, 1/2 mm. long. COLLAR - Glabrous. SHEATH - Glabrous, papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, unbranched. OUTSTANDING CHARACTERS - Small auricle, growth in very early spring.

2. *Agropyron smithii* Rydb. WESTERN WHEATGRASS



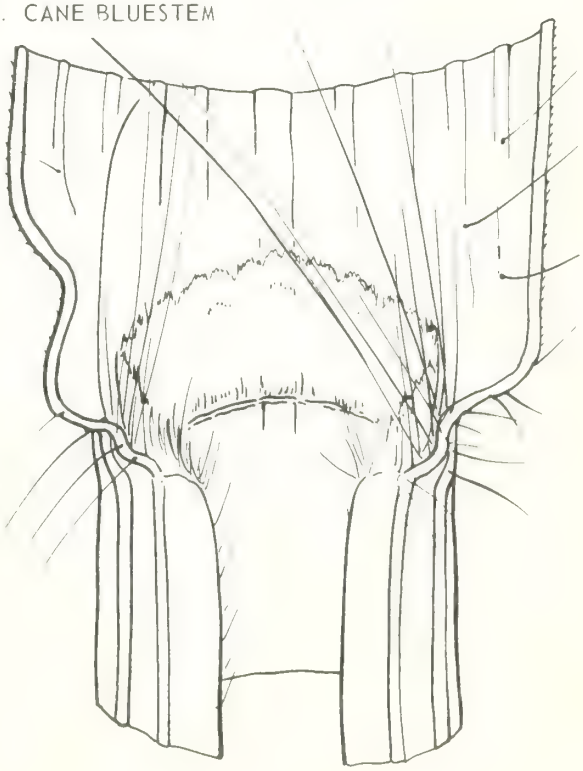
Erect, individual plants to an open sodgrass. VERNATION - Curled. BLADES - Usually rolled blue-green, erect, narrow pointed; rough dorsally, pubescent ventrally; veins each side of midrib, 6-8; ribs prominent ventrally; margin toothed, midrib not prominent; 2-3 mm. wide, 5-15 cm. long. AURICLE - Small, 1/4 - 1/2 mm., usually brownish-red. LIGULE - Collar-like (membranous), small, 1/4 - 1/2 mm.; truncate-toothed. COLLAR - Smooth, divided. SHEATH - Smooth, round, veined; lower pinkish to red. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous, rhizomatous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Auricles small, blade ribs prominent dorsally, growth usually sod, blade color usually a blue-green.

3. *Agrostis alba* L. REDTOP



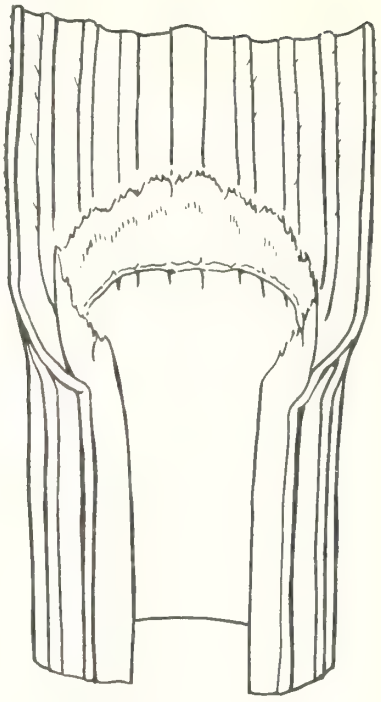
Erect, open sod. VERNATION - Folded (also reported as curled). BLADES - Flat, erect, narrow, pointed, wider at base; rough ventral and dorsal; veins each side midrib, 3; ribs prominent dorsally and ventrally; margin toothed; midrib prominent dorsally; 3-5 mm. wide, 3-8 cm. long. AURICLE - None. LIGULE - Membranous, small, 1-3 mm., obtuse-entire to slightly toothed. COLLAR - Glabrous, divided. SHEATH - Glabrous, round, frequently purplish-red. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Rhizomatous. CULM - Round, occasionally branched. OUTSTANDING CHARACTERS - Ligule small, 1-2 mm.; obtuse-entire, blades flat, wide tapered to point, glabrous, culm frequently reddish-purple at maturity, rhizomatous.

4. *Andropogon barbinodis* Lag. CANE BLUESTEM



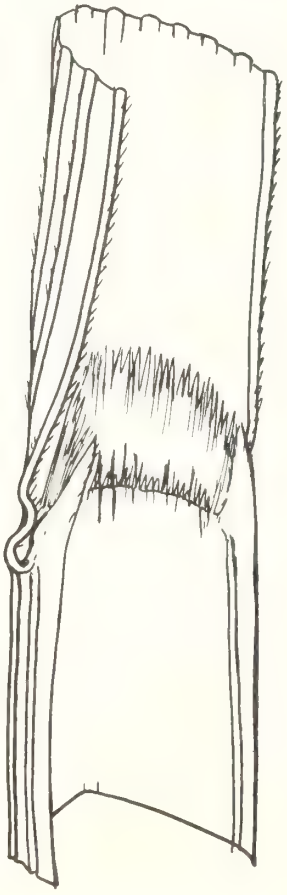
Erect, small bunchgrass. VERNATION - Curled. BLADES - Flat, narrow, pointed; reddish; rough ventrally and dorsally; margin white, toothed; midrib prominent dorsally; 2-5 mm. wide, 8-20 cm. long. AURICLE - None. LIGULE - Membranous, 2-3 mm., obtuse-lacerate, occasionally long hairs on back, 3-5 mm. COLLAR - Smooth, divided. SHEATH - Round, reddish, smooth, hyaline margin, veined. NODES - Woolly. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, usually branched, reddish. OUTSTANDING CHARACTERS - Blade margin white; nodes woolly, culms large, usually branched. Mature plants usually reddish. Panicle large, cotton-like, awned.

5. *Andropogon cirratus* Hack. TEXAS BLUESTEM



Erect, small bunchgrass. VERNATION - Folded. BLADES - Old, flat; new, folded; erect, narrow, pointed; veins each side of midrib 2-3; midrib prominent dorsally; 2-4 mm. wide, 12-20 cm. long. AURICLE - None. LIGULE - Membranous, small, 1-2 mm., obtuse-entire. COLLAR - Glabrous. SHEATH - Glabrous, round. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, sparingly branched. OUTSTANDING CHARACTERS - Old growth blades usually flat. New growth blades folded, long, narrow.

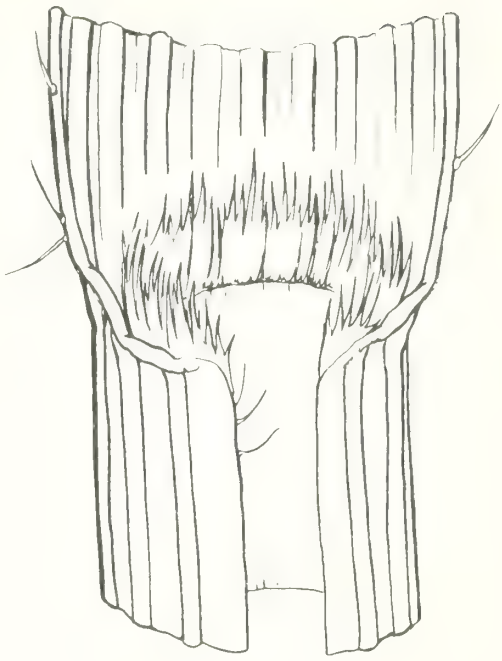
6. *Andropogon scoparius* Michx. LITTLE BLUESTEM



Erect, medium to large bunchgrass. VERNATION - Folded. BLADES - Flat to folded, narrow, dropping, pointed; rough, margin toothed; veins each side of midrib usually 4; ribs prominent ventrally and dorsally; midrib prominent dorsally; 2 mm. wide, 5-20 cm. long. AURICLE - None. LIGULE - Collar-like (membranous), small, 1/2 mm., occasionally to 2 mm., obtuse, finely lacerate. COLLAR - Glabrous, very small. SHEATH - Glabrous, flat, occasionally pinkish. NODES - Glabrous, reddish-brown at maturity. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Flat. OUTSTANDING CHARACTERS - Blades usually folded, long and narrow, twisted. Stems elliptical to flat. Ligule very small and difficult to observe.

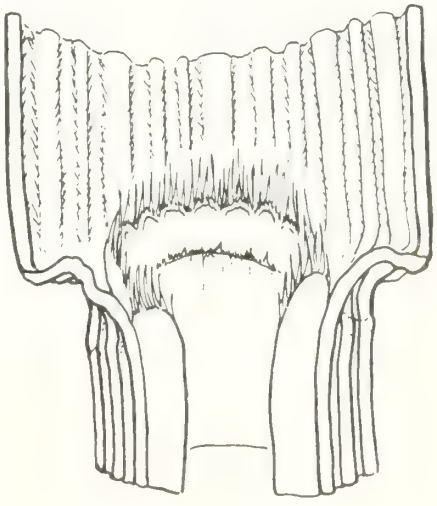
7. *Aristida adscensionis* L. SIXWEEKS THREE-AWN

Annual, erect, small bunchgrass. VERNATION - Folded. BLADES - Flat, narrow, short; glabrous, soft; veins each side of midrib, 3-4; ribs not prominent; margin glandular hairs at base; midrib not prominent; 1/2-1 mm. wide, 1-2 1/2 cm. long. AURICLE - None. LIGULE - Hairy, small 1/2 mm., long hairs, 2-3 mm. COLLAR - Hairy margin, glandular, 2-3 mm. SHEATH - Occasional hairs, papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous, superficial. CULM - Round, frequently branched. OUTSTANDING CHARACTERS - Annual. Collar with glandular hairs. Ligule hairy, very small 1/2 mm. Roots superficial. Blades narrow, short, usually margin glandular hairs. At maturity usually blown away. Awns, 1-2 cm.



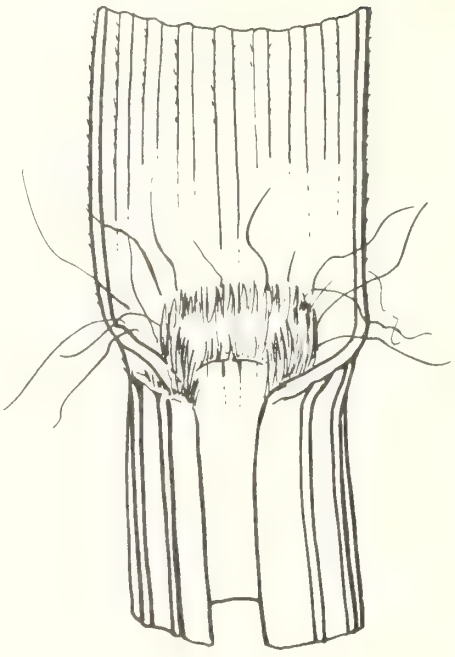
8. *Aristida divaricata* Humb. & Bonpl. POVERTY THREE-AWN

Erect, small bunchgrass. VERNATION - Clasped. BLADES - Rolled, erect, narrow, pointed; smooth; ribs prominent ventrally; margin toothed; midrib not prominent; 1/2-1 mm. wide, 5-15, occasionally 25 cm. long. AURICLE - None. LIGULE - Hairy, small 1/2-1 mm. COLLAR - Bearded, 1-2 mm. SHEATH - Glabrous, veined. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Collar and ligule bearded. Glades narrow, rolled, thread-like. Awns short 10-15 mm.



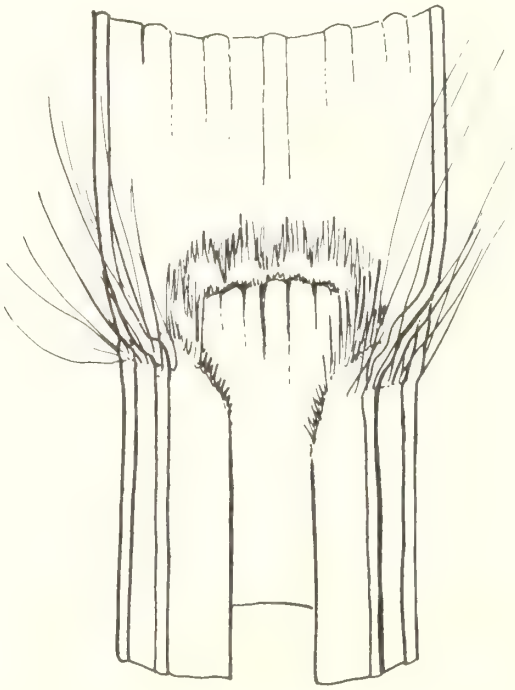
9. *Aristida glabrata* (Vasey) Hitchc. SANTA RITA THREE-AWN

Erect, small bunchgrass. VERNATION - Clasped. BLADES - Hairy ventrally on lower 1/4, 2-3 mm.; veins each side of midrib, 3; ribs prominent ventrally and dorsally; margin glabrous; midrib not prominent; 1 mm. wide, 5-18 cm. long. AURICLE - None. LIGULE - Hairy, small 1/2-1 mm., occasional hairs 2-3 mm. COLLAR - Glabrous, divided. SHEATH - Glabrous, veined, papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Elliptical, strongly branched. OUTSTANDING CHARACTERS - Blades long, narrow, usually rolled. Ligule hairy, small, and scattered hairs, 2-3 mm. Blades scattered hairs, 2-3 mm. dorsally. Awns, 2-4 cm. Culms branched.

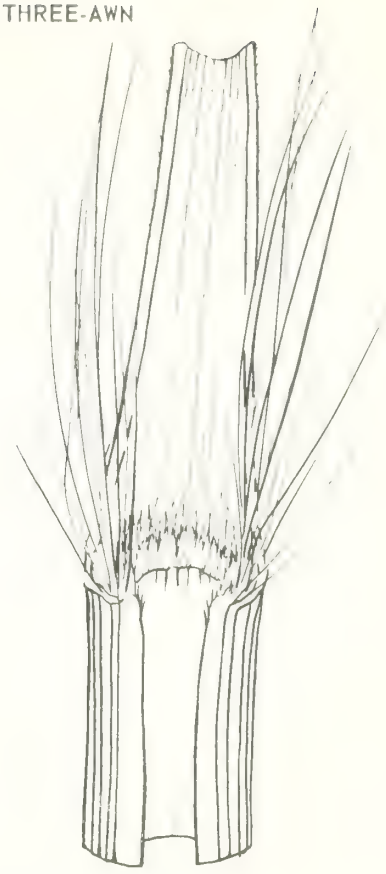


10. *Aristida glauca* (Nees) Walp. BLUE THREE-AWN

Erect, medium bunchgrass. VERNATION - Clasped. BLADES - Rolled, narrow, pointed; usually glabrous, stiff; veins and ribs indistinct; margin smooth; midrib prominent; 1/2 mm. wide, 15-25 cm. long. AURICLE - None. LIGULE - A collar, small 1/4-1/2 mm., truncate-ciliate. COLLAR - Ciliate front margin divided. SHEATH - Round, glabrous. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, usually branched. OUTSTANDING CHARACTERS - Blades rolled, narrow, long, pointed. Culms usually branched. Ligule ciliate, short. Awns 2-4 cm. long.

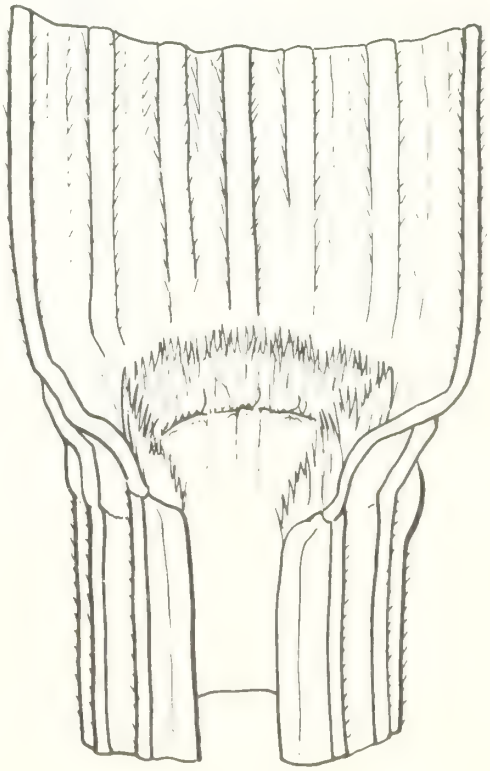


11. *Aristida longiseta* Steud. RED THREE-AWN



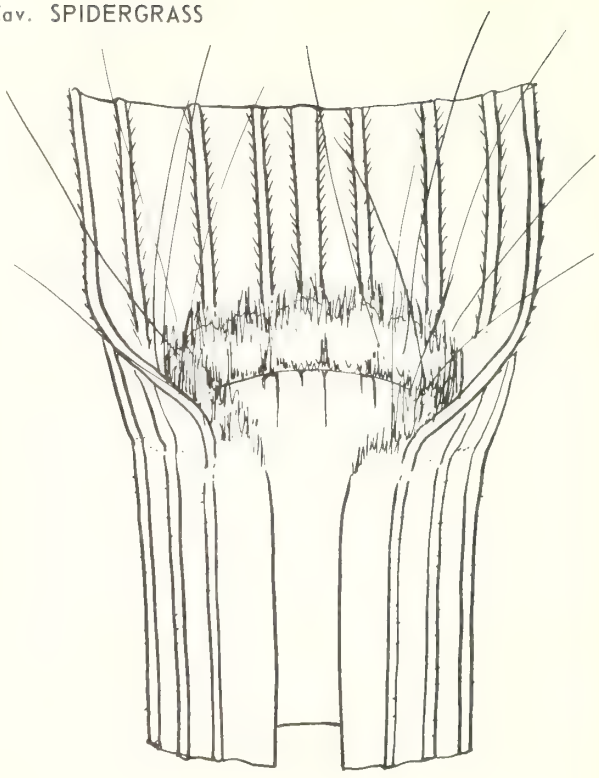
Erect, small bunchgrass. VERNATION - Clasped. BLADES - Rolled, narrow, long; rough ventrally, stiff; ribs not prominent; margin toothed; midrib not prominent; 1 mm. wide, 10-20 cm. long. AURICLE - None. LIGULE - Hairy, tufted, 1-2 mm. COLLAR - Hairy margin, divided. SHEATH - Round, veined, glabrous, papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Blades rolled, narrow, long. Ligule hairy, tufted, 1-2 mm. Awn 5-8 cm. long.

12. *Aristida purpurea* Nutt. PURPLE THREE-AWN



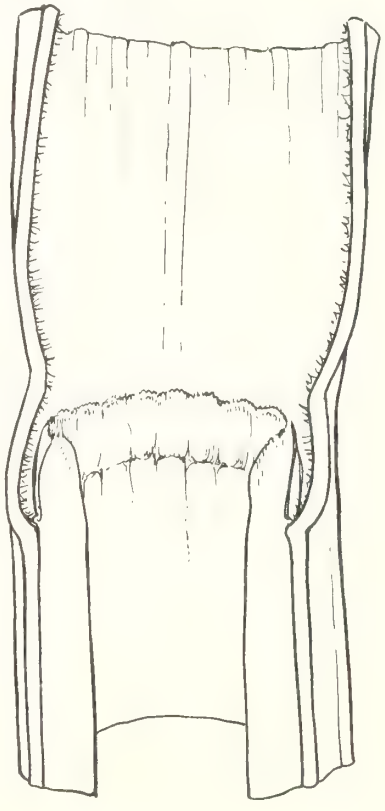
Erect, small bunchgrass. VERNATION - Folded. BLADES - Rolled, curved, pointed; rough dorsally and ventrally, occasionally hairy; ribs indistinct; margin occasionally hairy, 1/2 mm. wide, 2-8 cm. long. AURICLE - None. LIGULE - Hairy, 1-1 1/2 mm. COLLAR - Hairy margin, bearded. SHEATH - Glabrous, round. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Blades rolled, thread-like, curved, short. Collar bearded. Ligule conspicuous hairs. Awns purple, 2-5 cm.

13. *Aristida tenuipes* Cav. SPIDERGRASS



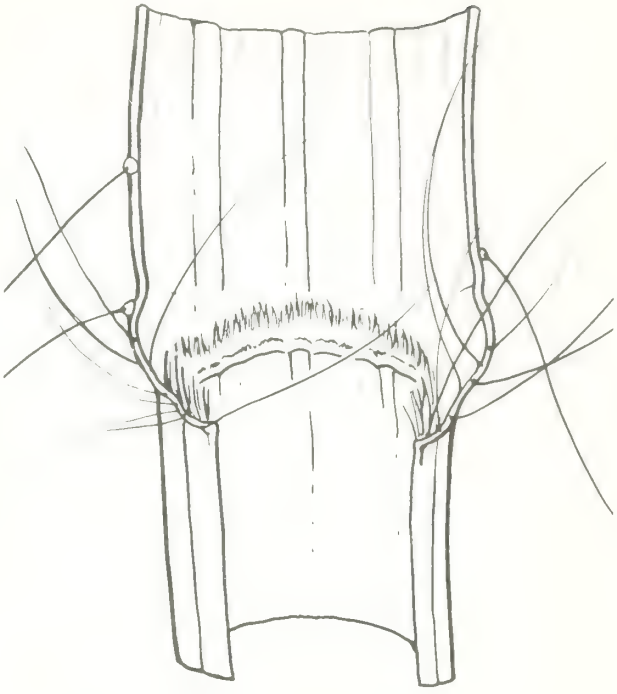
Erect, small bunchgrass. VERNATION - Folded. BLADES - Flat at base, tip rolled; rough, occasional hairs dorsally; veins each side of midrib, 2; ribs prominent ventrally and dorsally; margin toothed; midrib not prominent; 2 mm. wide, 5-20 cm. long. AURICLE - None. LIGULE - Hairy, small 1 mm. COLLAR - Hairy margin, 1 mm., divided. SHEATH - Glabrous, papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Elliptical, occasionally branched. OUTSTANDING CHARACTERS - Blades flat at base, narrow, long, ribbed. Ligule hairy, small. Collar hairy margin. Awns, 1 long and 2 short.

14. *Blepharoneuron tricholepis* (Torr.) Nash. PINE DROPSEED



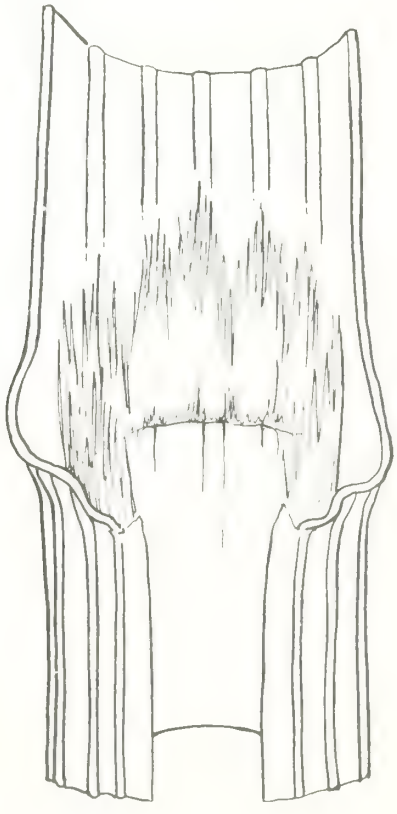
Erect, small bunchgrass. VERNATION - Folded. BLADES - Usually rolled, narrow, pointed; rough, stiff, ribs indistinct; margin toothed; midrib not prominent; 1 mm. wide, 5-10 cm. long. AURICLE - None. LIGULE - Membranous, very small, 1 mm., truncate-entire. COLLAR - Glabrous. SHEATH - Elliptical, glabrous, veined. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Blades long, narrow, usually rolled. Ligule small, truncate-entire. Few basal blades.

15. *Bouteloua aristidoides* (H.B.K.) Griseb. NEEDLE GRAMA



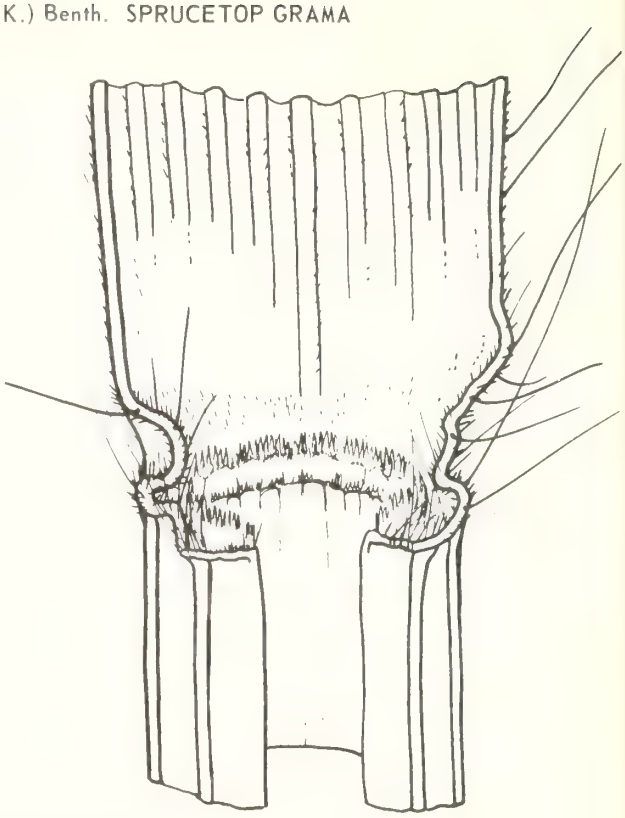
Annual semi-erect, small bunchgrass. VERNATION - Curled. BLADES - Flat, erect, narrow, pointed; blade hairy near collar; veins each side of midrib, 1-2; ribs indistinct; margin with grandular hairs near ligule, 2-4 mm.; midrib prominent ventrally; 1-2 mm. wide, 2-7cm. long. AURICLE - None. LIGULE - Hairy, small 1/2 mm. COLLAR - Glabrous. SHEATH - Glabrous, veined, elliptical. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Elliptical, branched. OUTSTANDING CHARACTERS - Annual. Ligule hairy. Blade margin glandular hairs. Stems branched. Awns short.

16. *Bouteloua barbata* Lag. SIXWEEKS GRAMA



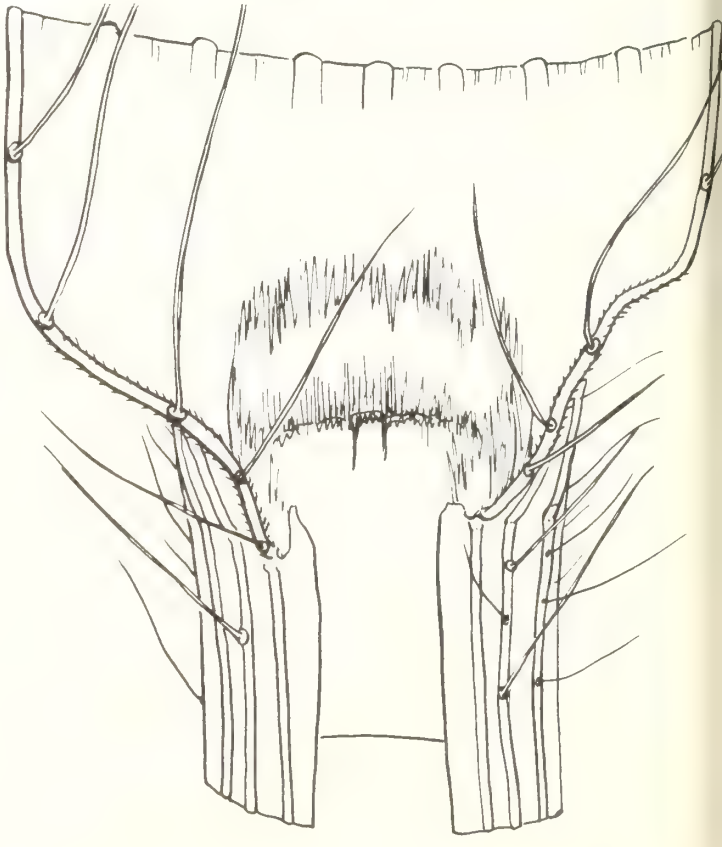
Annual, erect, small bunchgrass. VERNATION - Curled. BLADES - Flat, narrow, short; glabrous; veins each side of midrib, 2; ribs not prominent; margin glabrous; midrib not prominent; 1 mm. wide, 2-4 cm. long. AURICLE - None. LIGULE - Hairy, small 1 mm. COLLAR - Glabrous. SHEATH - Glabrous, veined, margin papery. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Branched, round. OUTSTANDING CHARACTERS - Annual. Roots superficial, blows away at maturity. Ligule hairy. Blades flat, narrow, short. Sheath margin papery. Awns short.

17. *Bouteloua chondrosioides* (H.B.K.) Benth. SPRUCETOP GRAMA



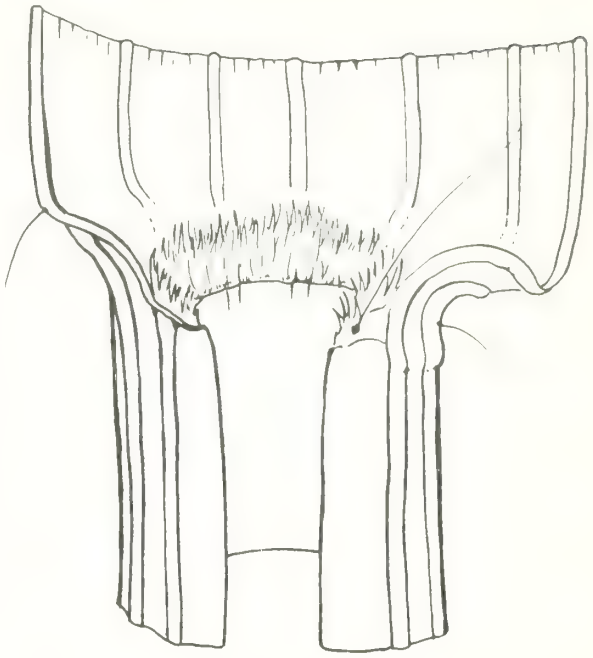
Erect, small bunchgrass. VERNATION - Clasped. BLADES - Flat, drooping, narrow, pointed; occasionally hairy ventrally and dorsally; veins each side of midrib, 4; ribs numerous, prominent ventrally and dorsally; margin with glandular hairs, midrib prominent ventrally; 2 mm. wide, 5-15 cm. long. LIGULE - Hairy, 1/4 mm. COLLAR - Hairy dorsally, margin divided. SHEATH - Round, veined, glabrous. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Glandular hairs on blade margin, dorsally and occasionally ventrally. Ligule hairy, small 1/4 mm. Spikelet villous, short and broad.

18. *Bouteloua curtipendula* (Michx.) Torr. SIDEOATS GRAMA



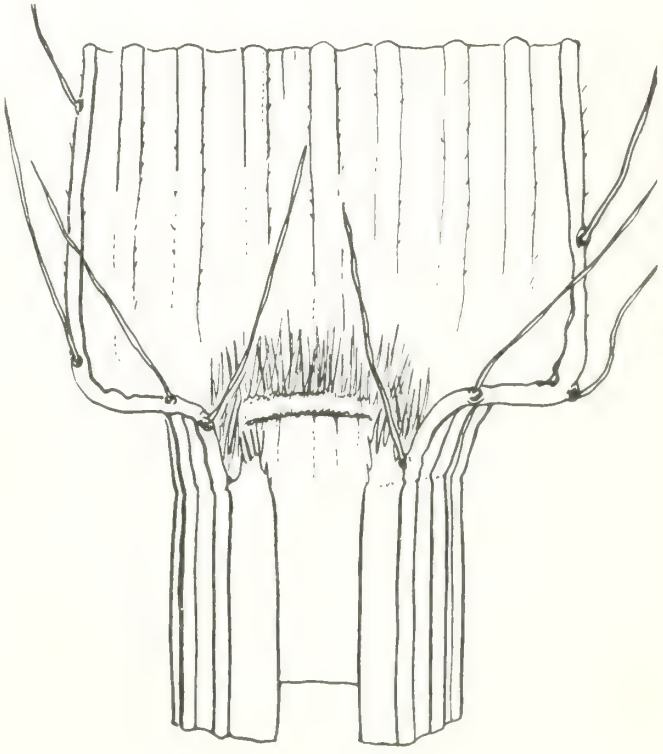
Erect, large bunchgrass. VERNATION - Curled. BLADES - Flat, long, drooping, narrow, pointed; rough dorsally; veins each side of midrib, 2-3; ribs not prominent; margin toothed, glandular hairs; midrib not prominent; 2-3 mm. wide, 5-20 cm. long. AURICLE - None. LIGULE - Membranous, small 1 mm., truncate-lacerate. COLLAR - Hairy margin and occasionally glandular. SHEATH - Glabrous, veined, papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Short rhizomes. CULM - Elliptical to round occasionally branched. OUTSTANDING CHARACTERS - Blade and collar margins with conspicuous glandular hairs. Rachis zigzag. Mature plants reddish-brown.

19. *Bouteloua eriopoda* Torr. BLACK GRAMA



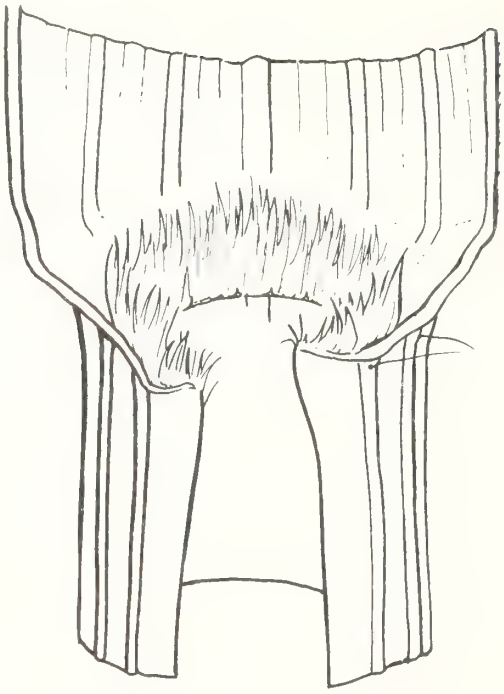
Erect to generally decumbent. VERNATION - Curled. BLADES - Flat, narrow, drooping, pointed; soft, hairy ventrally; veins each side of midrib, usually 2; rib not prominent; margin glandular hairs, 3-5 mm., midrib not prominent; 1-2 mm. wide, 3-8 cm. long. AURICLE - None. LIGULE - Hairy, small, 1/2 mm. COLLAR - Glabrous or with scattered hairs. SHEATH - Round, glabrous, NODES - Sparsely pubescent to glabrous. INTERNODES - Woolly. ROOTS - Fibrous. CULM - Round, branch at node, woolly. OUTSTANDING CHARACTERS - Blade margin glandular hairs. Internodes canescent. Culm roots at nodes and produces new plants. Old plants surrounded by new plants connected with stolons. Lower stems remain green year long.

20. *Bouteloua filiformis* (Fourn.) Griffiths. SLENDER GRAMA



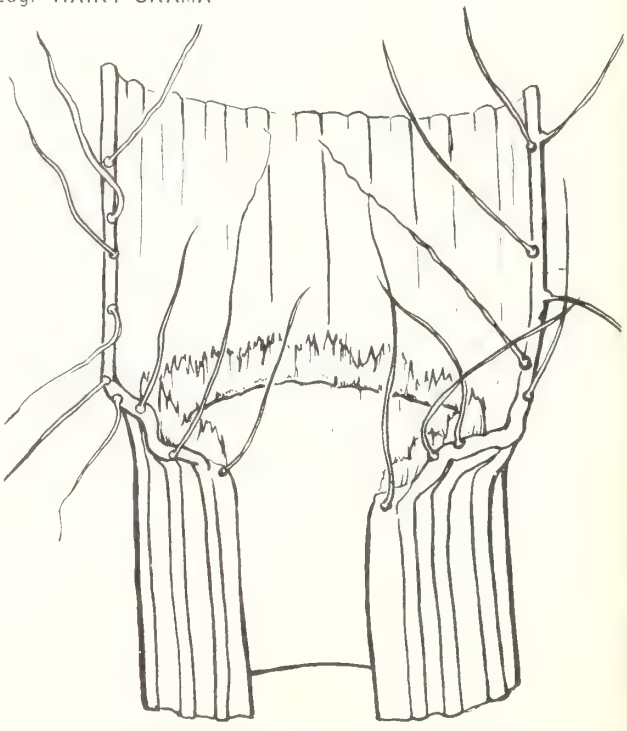
Erect, small bunchgrass. VERNATION - Curled. BLADES - Flat, narrow, pointed; margin rough, glandular hairs; veins each side of midrib, 2-3; ribs prominent (with lens) ventrally and dorsally, midrib prominent ventrally; 1-2 mm. wide, 5-8 cm. long. AURICLE - None. LIGULE - Hairy, small 1/2 mm., ciliate. COLLAR - Hairy margin. SHEATH - Glabrous, papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Blade margin glandular hairs. Ligule ciliate, small 1/2 mm. Blades narrow, long.

21. *Bouteloua gracilis* (H.B.K.) Lag. BLUE GRAMA



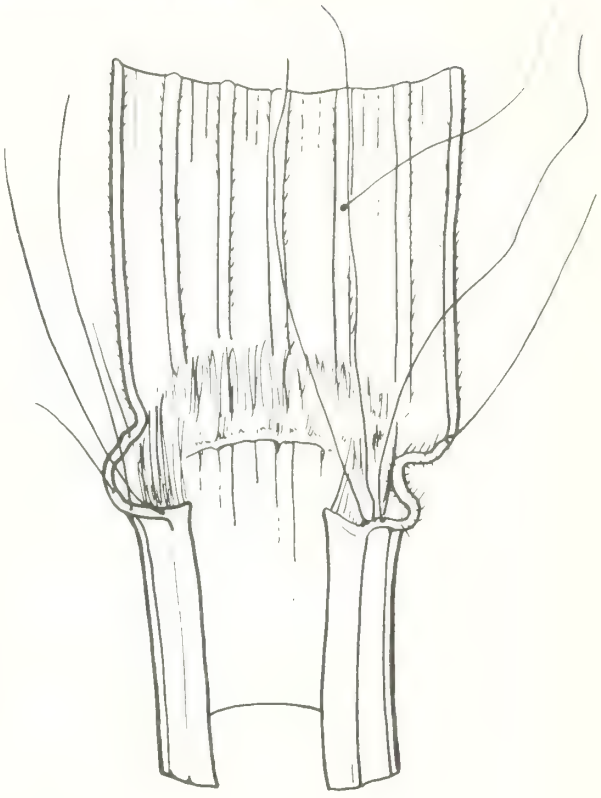
Erect, open sod or mat. VERNATION - Clasped. BLADES - Flat, drooping, narrow, pointed; rough ventrally, veins each side of midrib usually 2; veins prominent ventrally and dorsally, margin toothed; sparsely pilose below; 2-3 mm. wide, 5-15 cm. long. AURICLE - None. LIGULE - Small 1/2 mm. mostly of hairs. COLLAR - Glabrous (smooth, not pubescent or hairy). SHEATH - Round, glabrous, veined. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous, short rhizomes. CULM - Round, not branched. OUTSTANDING CHARACTERS - Blade in bud clasped. Blades flat, narrow, long drooping, glabrous. Usually semi-sod. Old growth blades curled.

22. *Bouteloua hirsuta* Lag. HAIRY GRAMA



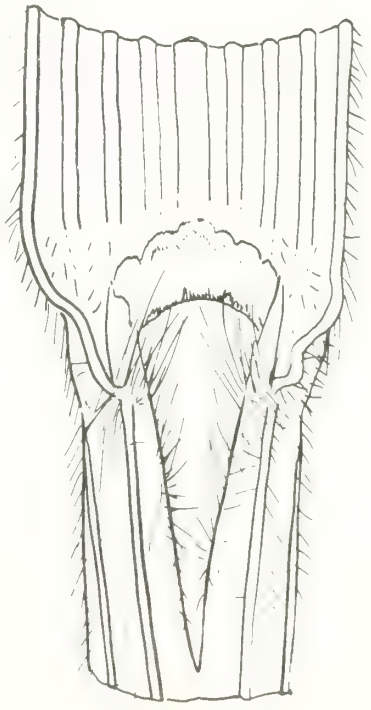
Erect, small bunchgrass. VERNATION - Clasped. BLADES - Flat, drooping, narrow, pointed; rough, hairy dorsally; veins each side of midrib, 3-4 ribs indistinct; margin glandular hairs; midrib not prominent; 1-3 mm. wide, 3-10 cm. long. AURICLE - None. LIGULE - Membranous, small 1/4 mm. with occasional marginal hairs; truncate ciliate. COLLAR - Hairy with glandular marginal hairs. SHEATH - Veined, round with papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Not branched, round. OUTSTANDING CHARACTERS - Blades margin with glandular hairs. Rachis extends beyond terminal spikelet. Collar margin with glandular hairs.

23. *Bouteloua rothrockii* Vasey ROTHROCK GRAMA



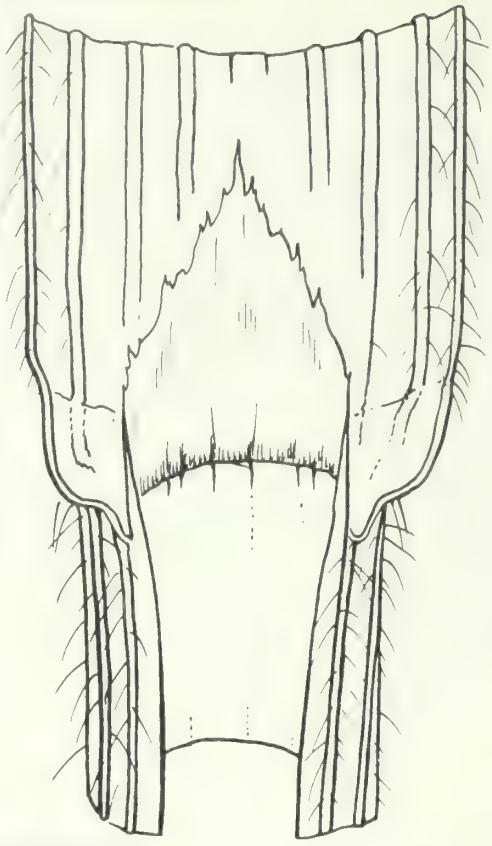
Erect to semi-erect, small bunchgrass. VERNATION - Curled. BLADES - Flat, drooping, narrow, long, pointed; rough, hairy ventrally and dorsally; veins each side of midrib 2; ribs numerous, not prominent; margin glandular hairs, toothed; midrib prominent dorsally; 2 mm. wide, 5-15 cm. long. AURICLE - None. LIGULE - Hairy, tufted, 2-4 mm. COLLAR - Hairy margin, divided. SHEATH - Glabrous, papery margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Glandular hairs on blade margin, dorsally and occasionally ventrally. Ligule and collar hairy. Spikelets 3-8, slender.

24. *Bromus anomalus* Rupr. NODDING BROME



Erect, small bunchgrass. VERNATION - Curled. BLADES - Flat, wide, long, drooping; occasionally hairy dorsally, 2-4 mm.; veins each side of midrib, 3; ribs prominent ventrally and dorsally; margin toothed; midrib prominent dorsally and ventrally; 2-8 mm. wide, 15-40 cm. long. AURICLE - None. LIGULE - Membranous, small 1/2 mm., truncate-toothed. COLLAR - Glabrous, divided. SHEATH - Ribbed, generally closed, glabrous to hairy on margin, the lower sheaths sometimes retrorsely hispid. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Sheath usually closed completely. Blades flat and sheath with prominent ribs. Blades wide, long, drooping. Ligule membranous, 1/2 mm. truncate-toothed. Blade midrib prominent dorsally and ventrally.

25. *Bromus arizonicus* (Shear.) Stebbins. ARIZONA BROME

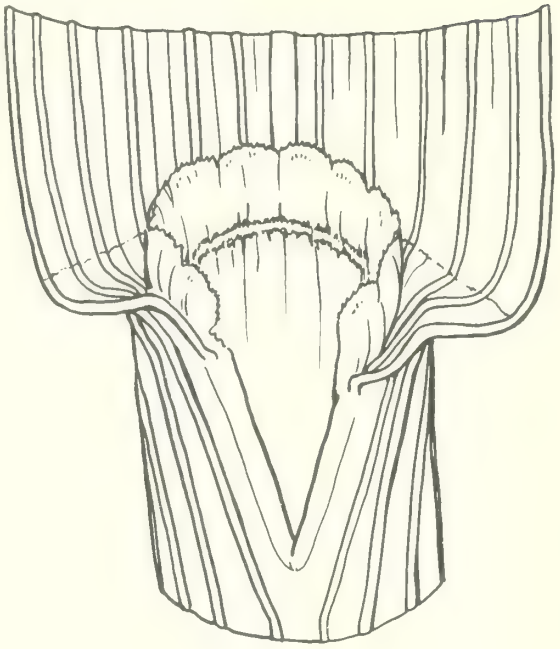


Erect, annual. VERNATION - Curled. BLADES - Flat, wide, long; hairy ventrally and dorsally; veins each side of midrib, 2-3; ribs prominent ventrally and dorsally; margin hairy; midrib prominent dorsally; 4-6 mm. wide, 10-20 cm. long. AURICLE - None. LIGULE - Membranous, hyaline, large 2-5 mm., obtuse-lacerate. COLLAR - Glabrous, divided. SHEATH - Closed, hairy. NODES - Glabrous. INTERNODES - Glabrous, veined. ROOTS - Fibrous, annual. CULM - Round, not branched. OUTSTANDING CHARACTERS - Annual. Sheath closed. Blades hairy. Ligule hyaline, large 2-5 mm., obtuse-lacerate. Awns. 5-10 mm.

26. *Bromus ciliatus* L. FRINGED BROME

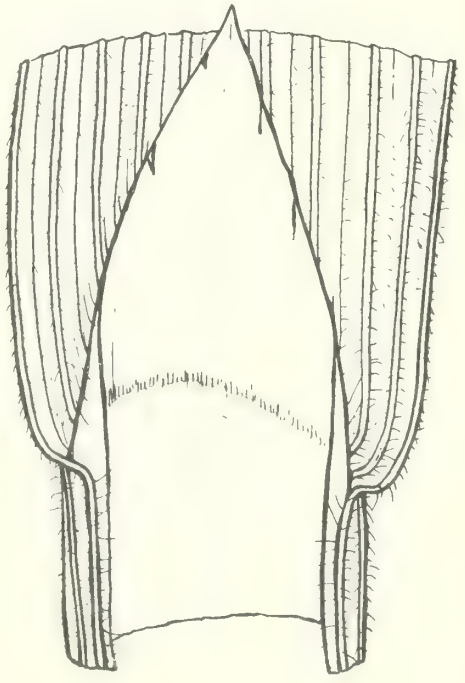
Erect, small bunchgrass, panicle drooping. VERNATION - Curled. BLADES - Flat, narrow, long, drooping; hairy; veins each side of midrib, 2-3; ribs prominent ventrally and dorsally; midrib prominent dorsally and ventrally; 2-8 mm. wide, 15-30 cm. long. AURICLE - None. LIGULE - Membranous, small 1/2-1 mm., truncate-notched. COLLAR - Hairy on margin. SHEATH - Hairy veined, usually closed lower 2/3. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Sheath closed lower 2/3. Ligule truncate-entire, 1/2-1 mm Conspicuous soft hairs over plant. Midrib prominent dorsally and ventrally.

27. *Bromus inermis* Leyss. SMOOTH BROME



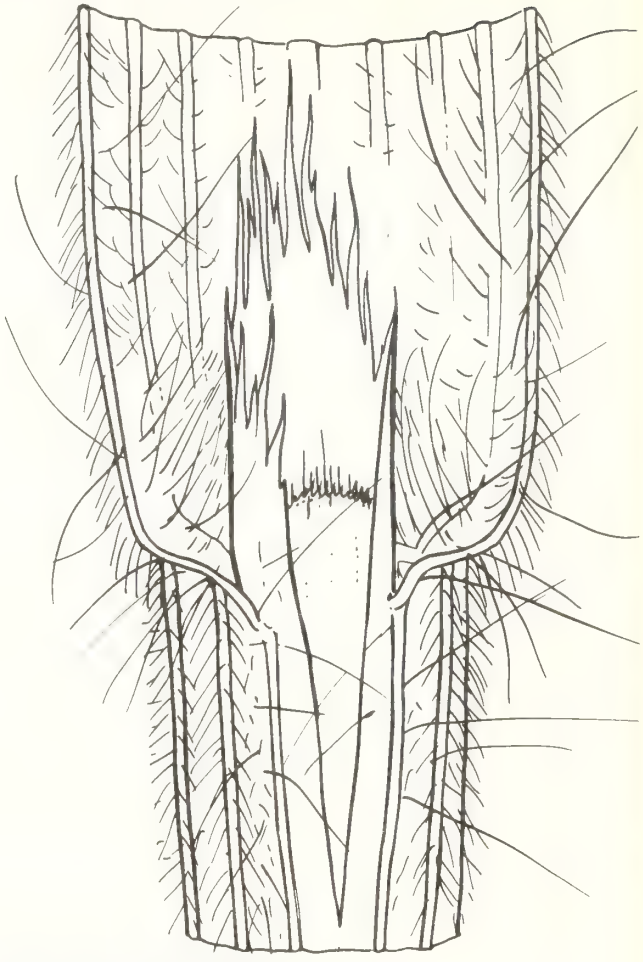
Large erect bunchgrass. VERNATION - Curled. BLADES - Flat, wide, drooping, usually a W on blade; rough ventrally and dorsally; veins each side of midrib, 5-6; rib prominent ventrally and dorsally; midrib prominent dorsally; 4-5 mm. wide, 10-20 cm. long. AURICLE - None. LIGULE - Membranous, small 1/2 mm. COLLAR - Glabrous, divided. SHEATH - Closed, sometimes hairy, veined, round, papery margin. NODES - Occasionally pubescent. INTERNODES - Glabrous, veined. ROOTS - Short rhizomes. CULM - Round, not branched, large. OUTSTANDING CHARACTERS - Sheath closed. The letter W or M on blades. Blades large, flat, long ribbed.

28. *Bromus rubens* L. RED BROME



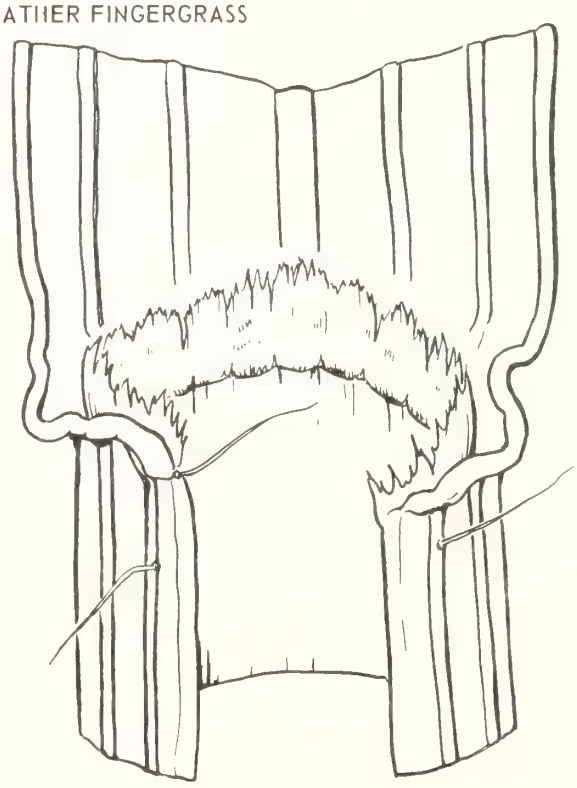
Erect to semi-decumbent, annual. VERNATION - Curled. BLADES - Flat, pointed; hairy dorsally and ventrally; veins each side midrib, 2-3; ribs prominent ventrally and dorsally; blade margin smooth; midrib prominent, 1-2 mm. wide, 2-6 cm. long. AURICLE - None. LIGULE - Membranous, 1/2-3 mm. long, acute-lacerate. COLLAR - Smooth. SHEATH - Pubescent, papery margin, round, usually closed. NODES - Glabrous. INTERNODES - Occasionally puberulent near nodes. ROOTS - Fibrous, weak. CULM - Not branched, round. OUTSTANDING CHARACTERS - Winter annual. Blades short, narrow, flat. Midrib prominent ventrally. Ligule acute-lacerate. Awns 1/2-1 cm. Head at maturity reddish color.

29. *Bromus tectorum* L. DOWNY CHESS, CHEATGRASS BROME



Semi-erect, small bunchgrass, annual. Heads open, drooping. VERNATION - Curled. BLADES - Flat twisted, drooping, blunt pointed; hairy ventrally and dorsally, soft; veins each side of midrib, 2-3; ribs indistinct; margin hairy; midrib prominent ventrally; 2-4 mm. wide, 5-10 cm. long. AURICLE - None. LIGULE - Membranous, collar-like, small 1-2 mm., obtuse-lacerate, paper-like. COLLAR - Smooth, divided. SHEATH - Woolly, round, closed. NODES - Glabrous, dark in color. INTERNODES - Glabrous. ROOTS - Shallow, fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Awn, 1-2 cm. Winter annual. Fire hazard. Sheath growth together. Ligule very thin, obtuse-lacerate. Woolly over most of plant, soft to touch. In northern climates grows in spring and fall. Excellent for lambing.

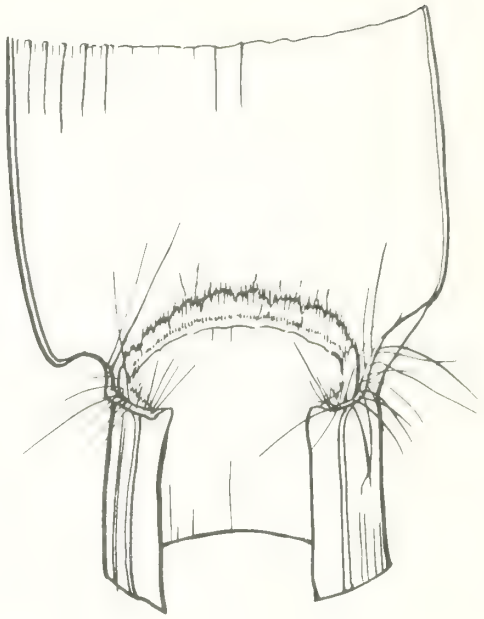
30. *Chloris virgata* Swartz. FEATHER FINGERGRASS



Semi-erect, annual small bunchgrass. VERNATION - Curled. BLADES - Flat, wide, long; occasionally glandular hairs dorsally near base, 2-3 mm.; veins each side of midrib, 3; ribs numerous, not prominent; margin often straw colored; midrib prominent ventrally; 3-6 mm. wide, 8-15 cm. long. AURICLE - None. LIGULE - Membranous, small, 1 mm., truncate-ciliate. COLLAR - Glabrous. SHEATH - Glabrous, hyaline margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous, annual. CULM - Elliptical, branched at base. OUTSTANDING CHARACTERS - Annual. Blades flat, wide, occasionally glandular hairs dorsally. Ligule 1 mm., truncate-ciliate. Blade midrib prominent ventrally.

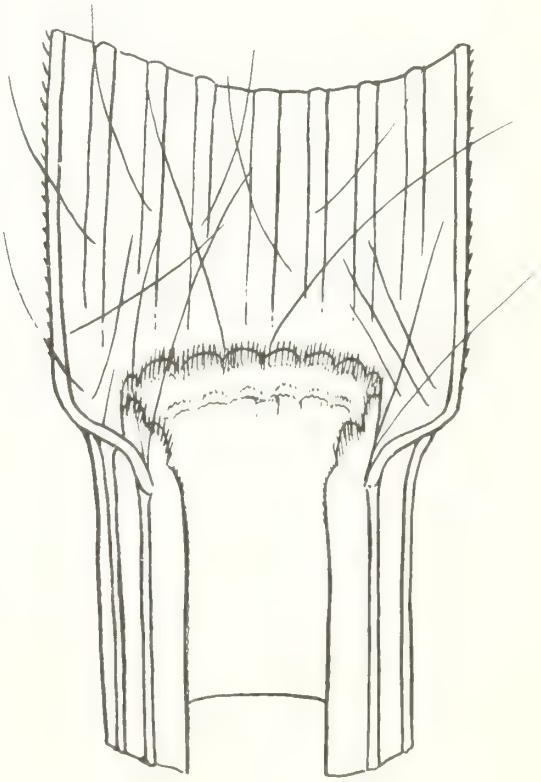
31. *Cynodon dactylon* (L) Pers. BERMUDAGRASS

Decumbent, sodgrass. VERNATION - Curled. BLADES - Flat, wide, short, usually glabrous; veins each side of midrib, 2; ribs not prominent; margin white, midrib prominent dorsally; 1-4 mm. wide, 2-6 cm. long. AURICLE - None. LIGULE - Hairy, medium, 1 mm., with scattered long hairs. COLLAR - Usually glabrous, occasionally with long hairs. SHEATH - Usually glabrous, hyaline margin, often with tufts of hair at the summit. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Rhizomatous. CULM - Elliptical, branched, stoloniferous. OUTSTANDING CHARACTERS - Culms, stoloniferous, branched. Ligule hairy. Blade flat, short, wide. Growth decumbent except flower stalks.

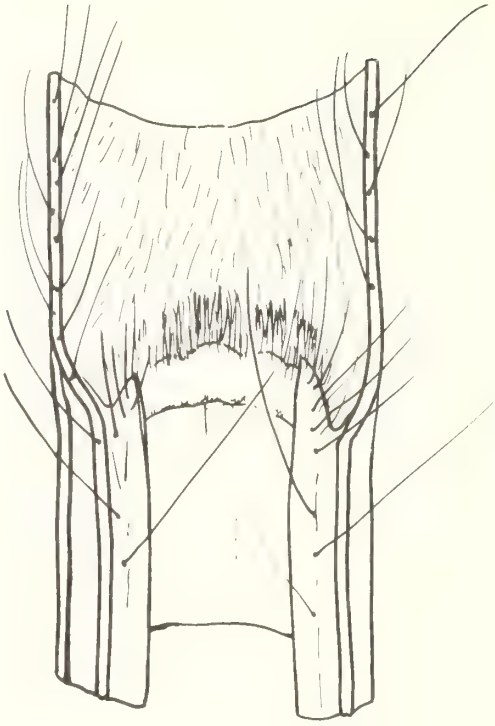


32. *Distichlis stricta* (Torr.) Rydb. DESERT SALTGRASS

Erect, semi-sodgrass. VERNATION - Clasped. BLADES - Flat to rolled, erect, narrow, pointed; hairy ventrally, frequently with salt deposits; veins each side of midrib, 3; ribs prominent dorsally; margin toothed; midrib prominent ventrally; 2-3 mm. wide at base, 1-6 cm. long. AURICLE - None. LIGULE - Hairy, small 1/2-1 mm. COLLAR - Occasionally hairy margin 1-2 mm. SHEATH - Smooth, round, paper margin. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Rhizomatous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Rhizomatous. Blades usually rolled at tip, short. Lower culms and rhizomes conspicuously shiny.

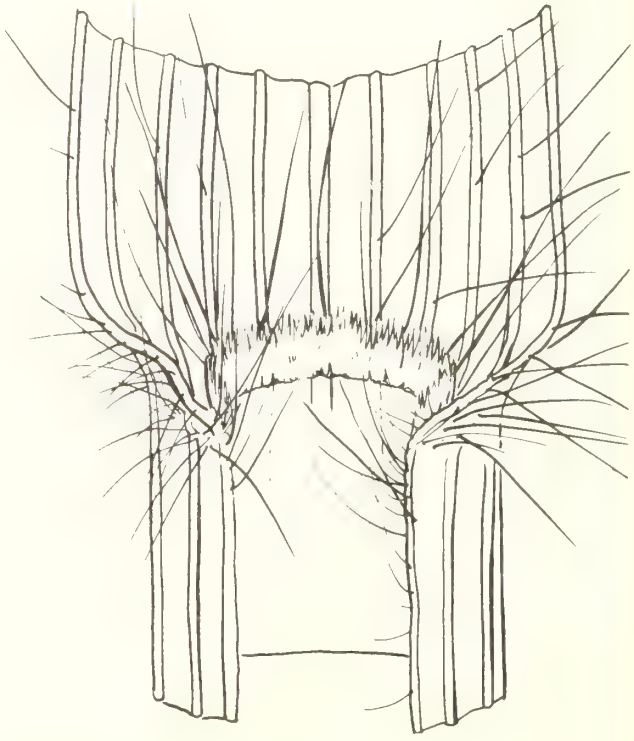


33. *Elyonurus barbiculmis* Hack. WOOLSPIKE



Erect, medium bunchgrass. VERNATION - Folded. BLADES - Rolled, narrow, long, hairy, ventrally, pilose, 3-5 mm.; ribs prominent dorsally; midrib not prominent; 1 mm. wide, 15-30 cm. long. AURICLE - None. LIGULE - Hairy, small 1 mm., front pilose, 2-5 mm. COLLAR - Glabrous, divided. SHEATH - Glabrous, veined. NODES - Glabrous. INTERNODES - Pubescent to villous below node. ROOTS - Fibrous. CULM - Round, branched. OUTSTANDING CHARACTERS - Ligule hairy, front pilose, 2-5 mm. Stems pubescent below node. Blades narrow, long rolled, hairy ventrally. Culms branched; heads silvery, densely pilose.

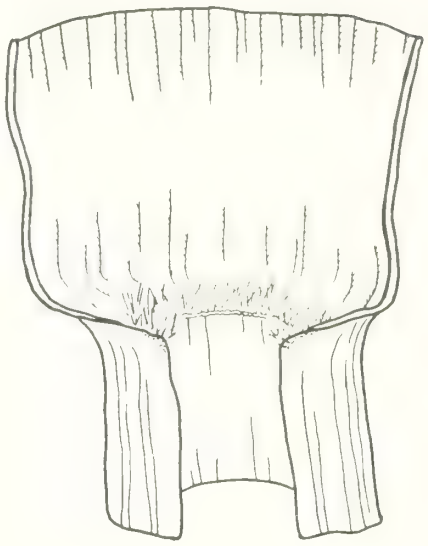
34. *Eragrostis intermedia* Hitchc. PLAINS LOVEGRASS



Erect, medium bunchgrass. VERNATION - Curled. BLADES - Flat, long, narrow, scattered hairs; veins each side of midrib, 3-4; ribs prominent ventrally and dorsally; margin smooth; midrib prominent dorsally; 2 mm. wide, 10-30 cm. long. AURICLE - None. LIGULE - Membranous, small 1/2 mm., truncate-ciliate, with long conspicuous hairs, 3-5 mm. COLLAR - Hairy on margin. SHEATH - Glabrous, veined. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Blades flat, long narrow. Conspicuous ribs on blade and sheath. Ligule membranous with long hairs. Collar bearded. Culm elliptical.

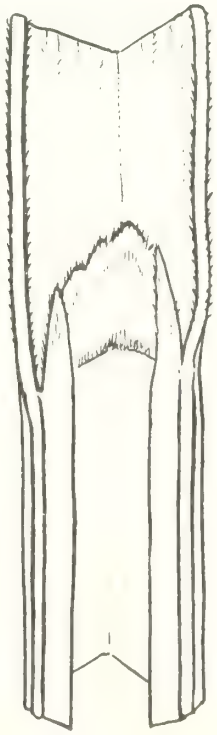
35. *Eragrostis lehmanniana* Nees. LEHMANN LOVEGRASS

Erect, large bunchgrass. VERNATION - Curled. BLADES - Flat, drooping, wide, long, narrow, pointed; glabrous, soft; veins each side of midrib, 3; ribs prominent ventrally and dorsally; margin glabrous; midrib not prominent, 3-4 mm. wide, 12-15 cm. long. AURICLE - None. LIGULE - Hairy or membranous, truncate-ciliate, 1/2-1 mm. COLLAR - Hairy margin, 2-3 mm. SHEATH - Round, veined, frequently bearded at base. NODES - Occasionally pubescent. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, occasionally branched. OUTSTANDING CHARACTERS - Blades flat, long. Blade ribs prominent. Collar margin hairy, 2-3 mm. Ligule truncate-ciliate, 1/2-1 mm. Large leafy bunch. Culm round.

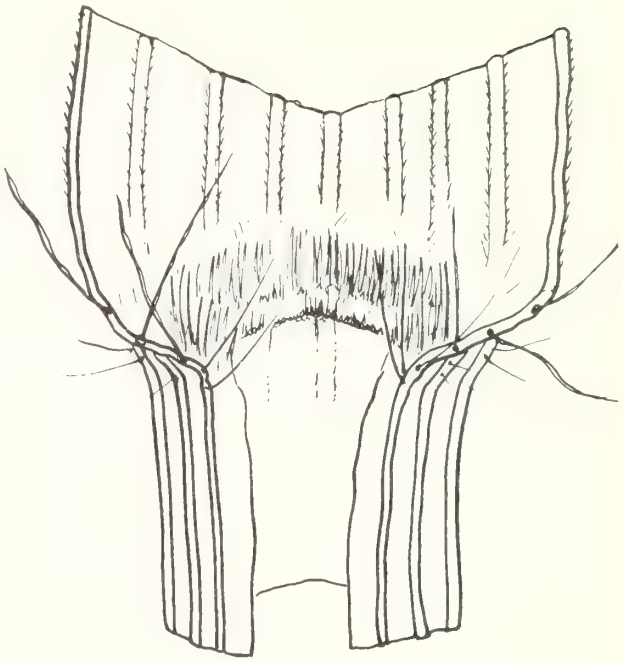


36. *Festuca arizonica* Vasey. ARIZONA FESCUE

Erect, large bunchgrass. VERNATION - Folded. BLADES - Rolled, drooping, very small; glabrous; ribs indistinct; margin toothed; midrib indistinct; 1/4-1/2 mm. wide, 10-30 cm. long. AURICLE - None. LIGULE - Membranous; very small, 1/4-1/2 mm.; acute-entire. COLLAR - Indistinct. SHEATH - Elliptical, pinkish above roots. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Long drooping, rolled, thread-like blades. Large bunches. Ligule very small and difficult to observe.

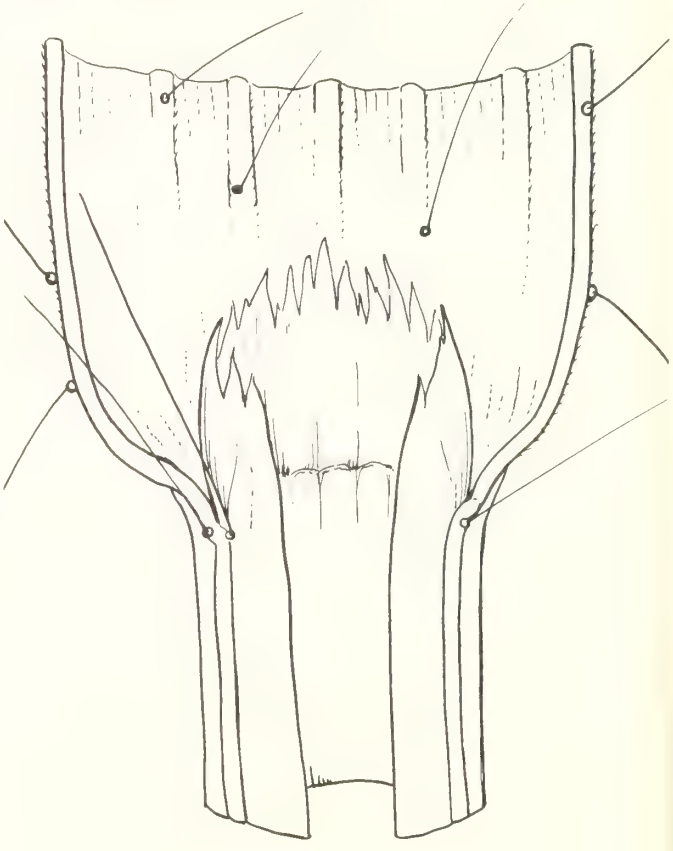


37. *Heteropogon contortus* (L.) Beauv. TANGLEHEAD



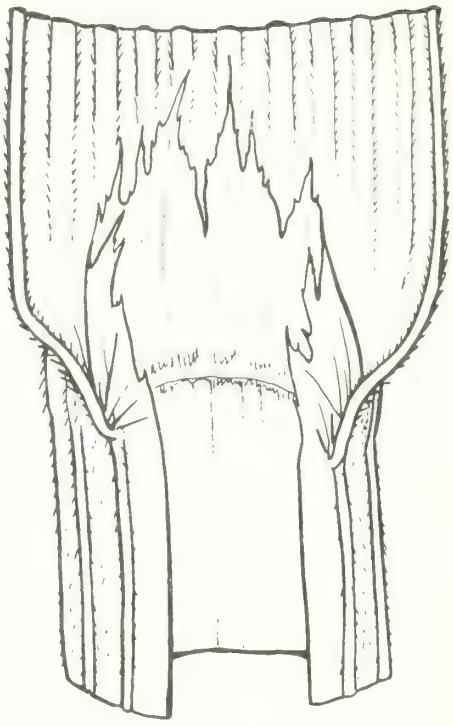
Erect, small bunchgrass. VERNATION - Folded. BLADES - Flat, wide; hairy occasionally ventrally; veins each side of midrib, 3-4; ribs not prominent; margin glandular at base, white; midrib prominent ventrally; 6-8 mm. wide, 6-15 cm. long. AURICLE - None. LIGULE - Hairy, lower half membranous, overall length 1 mm. COLLAR - Hairy margin, glandular, 2-4 mm. SHEATH - Flat, glabrous, veined. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Flat, not branched. OUTSTANDING CHARACTERS - Blades flat, wide, occasionally folded at base. Culm flat. Blade margin and collar with glandular hairs. Ligule hairy, small. Midrib prominent ventrally. Awns long, hairy, tangled mass.

38. *Hilaria belangeri* (Steud.) Nash. CURLYMESQUITE



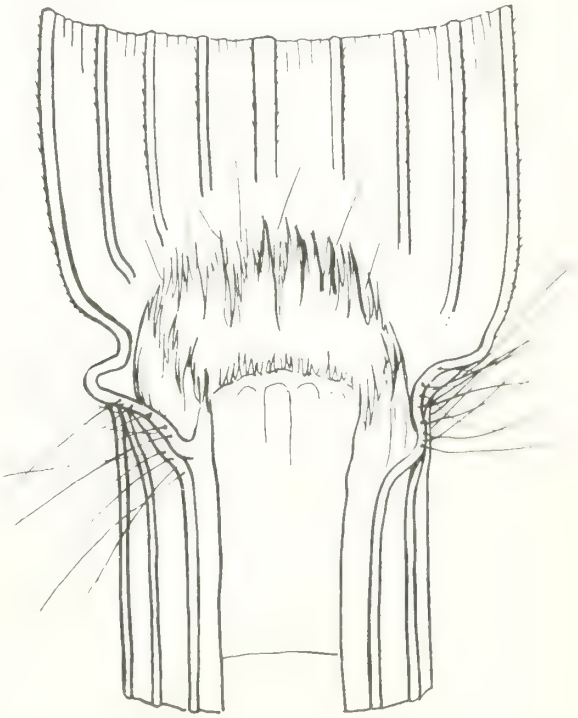
Open sodgrass. VERNATION - Curled. BLADES - Flat, curled, narrow, pointed, long; hairy, glandular; veins on each side of midrib, 2; ribs not prominent ventrally; 2 mm. wide, 5-20 cm. long. AURICLE - None. LIGULE - Membranous, large 2 mm.; truncate-lacerate. COLLAR - Glabrous. SHEATH - Glabrous, paper margin. NODES - Hairy. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, lower nodes grow roots and culms. OUTSTANDING CHARACTERS - Culms root at lower nodes. Nodes hairy. Blades with glandular hairs, 2-4 mm. Ligule 2 mm. truncate-lacerate.

39. *Hilaria jamesii* (Torr.) Benth. GALLETA



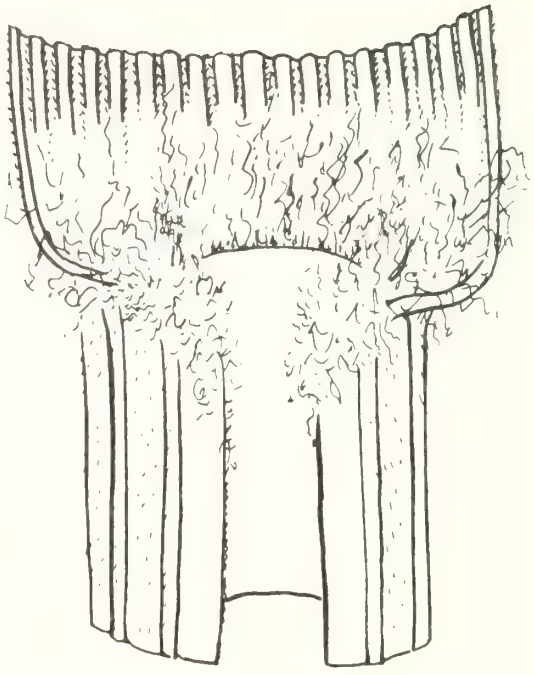
Erect, large bunchgrass. VERNATION - Curled. BLADES - Flat base, upper 2/3 often rolled, pointed; rough ventral and dorsal; veins each side of midrib, 3-4; ribs prominent dorsally; margin toothed; midrib not prominent; 3-5 mm. wide at base, 4-12 cm. long. AURICLE - None. LIGULE - Membranous, 1-3 mm., truncate-lacerate. COLLAR - Usually glabrous. SHEATH - Elliptical, veined. NODES - Pubescent to villous. INTERNODES - Often pubescent below node. ROOTS - Rhizomatous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Blades flat base, upper rolled. Rhizomatous. Nodes pubescent. Ligule 1-2 mm., truncate-lacerate. Culm base frequently semi-decumbent. Rachis zigzag.

40. *Hilaria mutica* (Buckl.) Benth. TOBOSA



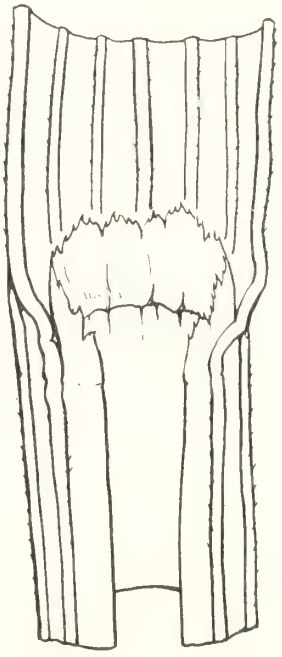
Big bunchgrass, semi-erect. VERNATION - Curled. BLADES - Flat to rolled; occasionally hairy ventrally; veins each side of midrib, 2-3; ribs prominent; midrib prominent ventrally; 2-4 mm. wide, 5-10 cm. long. AURICLE - None. LIGULE - Membranous, truncate-ciliate, 1-2 mm. COLLAR - Hairy margin. SHEATH - Glabrous, veined. NODES - Glabrous to pubescent. INTERNODES - Glabrous. ROOTS - Rhizomatous. CULM - Round, branched. OUTSTANDING CHARACTERS - Blade usually rolled. Growth semi-decumbent, large bunchgrass. Rhizomatous. Culms branch. Ligule truncate-ciliate.

41. *Hilaria rigida* (Thurb.) Benth. ex Scribn. BIG GALLETA



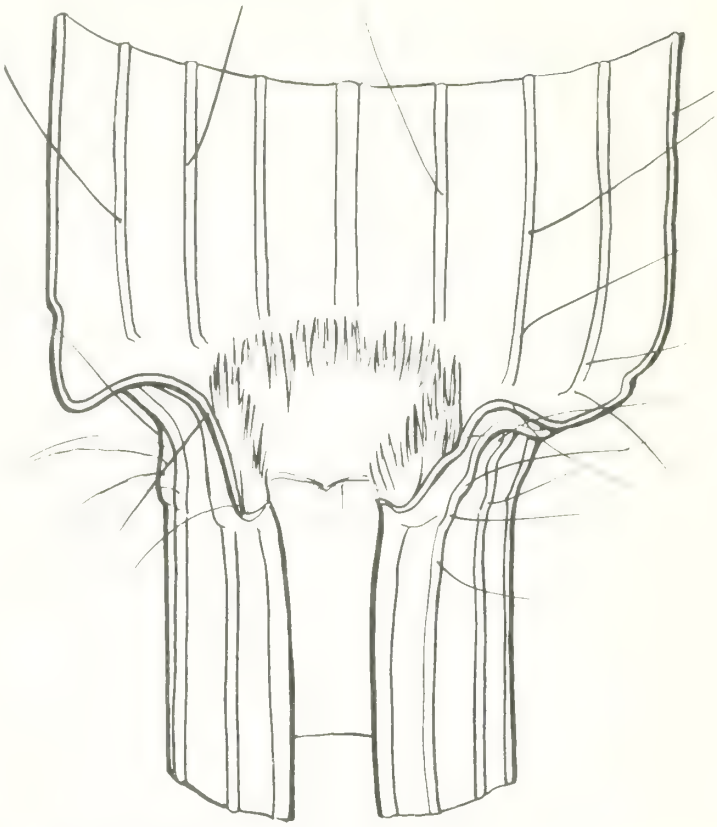
Erect, large bunchgrass. VERNATION - Curled. BLADES - Flat at base, upper part rolled, erect, narrow, pointed; smooth, stiff; veins each side midrib 2-4; ribs prominent ventrally, 6-8; margin toothed; midrib prominent dorsally; width 1-2 mm. length 4-10 cm. AURICLE - None. LIGULE - Hairy to woolly, small, 1 mm. COLLAR - Woolly. SHEATH - Round, margin woolly. NODE - Pubescent to woolly. INTERNODE - Woolly. ROOTS - Hard. scaly, rhizomatous. CULM - Round, branched. OUTSTANDING CHARACTERS - New growth sprouts at nodes. Ligule, nodes, collar, sheath and culms woolly.

42. *Koeleria cristata* (L.) Pers. JUNEGRASS



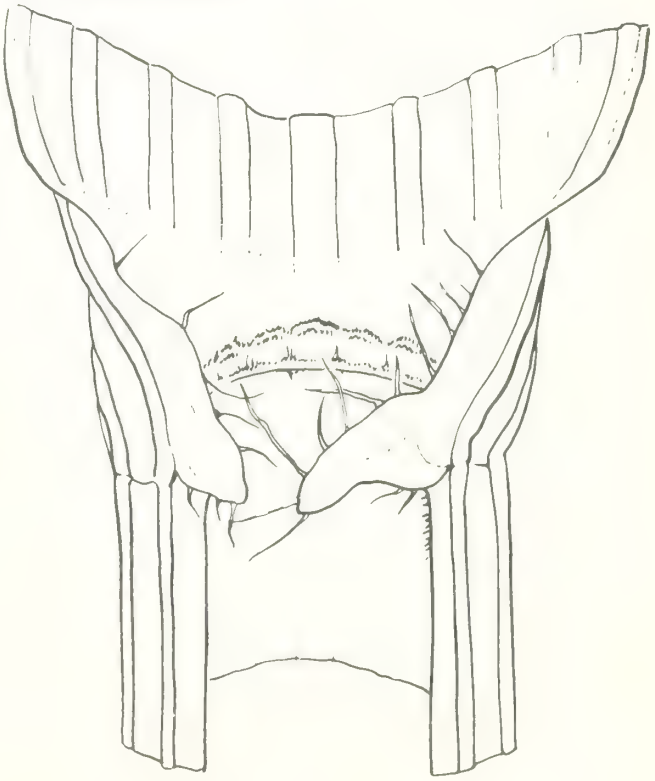
Erect, small bunchgrass. VERNATION - Folded. BLADES - Flat, drooping, narrow, pointed; rough ventrally, canescent dorsally, soft; veins each side of midrib usually 2; ribs prominent ventrally; margin toothed; width 2 mm., length 5-15 cm. AURICLE - None. LIGULE - Membranous, small 1/4-1/2 mm. truncate-ciliate. COLLAR - Glabrous to canescent. SHEATH - Usually canescent, round. NODES - Usually glabrous. INTERNODES - Usually canescent above node. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Blade flat, conspicuously ribbed ventrally, soft. Internode canescent near node. Ligule membranous, truncate-ciliate 1/2 mm.

43. *Leptochloa dubia* (H.B.K.) Nees. GREEN SPRANGLETOP



Erect, medium bunchgrass. VERNATION - Folded (reported in Colorado as curled). BLADES - Flat, wide, long, drooping; occasional hairs dorsally 2-5 mm., on lower one-third; veins on each side of midrib 2-3; ribs ventral and dorsal; margin toothed; midrib prominent ventrally; width 4-5 mm. length 15-25 cm. AURICLE - None. LIGULE - Hairy, small 1/2 mm., margin hairs 3-5 mm. COLLAR - Hairy margin, 3-5 mm. SHEATH - Glabrous, veined, papery margin. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Flat, not branched. OUTSTANDING CHARACTERS - Collar margin hairy. Culms flat. Ligule hairy, small 1/2 mm. occasional hairs 3-5 mm. Blades flat, wide, long drooping. Sheath veined, papery margin.

44. *Lolium perenne* L. PERENNIAL RYEGRASS

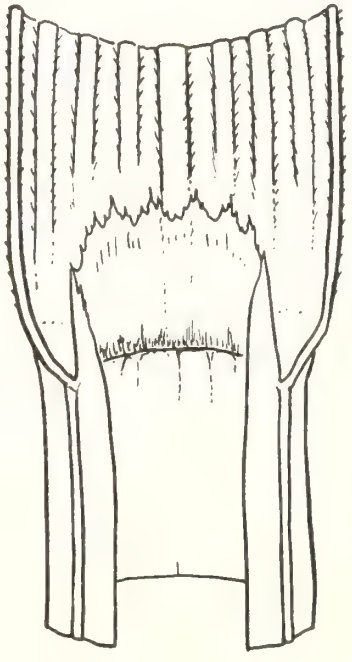


Erect to semi-erect, small bunchgrass. VERNATION - Folded. BLADES - Flat to folded, wide, long drooping; glabrous; glossy dorsally; veins each side of midrib 2-3; ribs prominent ventrally; margin glabrous; midrib prominent dorsally; width 3-4 mm., length 8-15 cm. AURICLE - Small, 1 mm. LIGULE - Membranous, medium 1-2 mm. acute-toothed. COLLAR - Glabrous, divided. SHEATH - Usually closed, strongly ribbed, glabrous. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Elliptical. OUTSTANDING CHARACTERS - Blades glossy ventrally. Auricle present clawed or reduced. Sheath usually closed and pinkish at base.

45. *Lycurus phleoides* H.B.K. WOLFTAIL

Erect, small bunchgrass. VERNATION - Folded. BLADES - Usually folded, drooping, glabrous; veins each side of midrib 2; margin white, toothed; ribs indistinct; midrib prominent dorsally; width 1 mm., length 3-10 cm. AURICLE - None. LIGULE - Membranous, large, 2-5 mm. acute-entire. COLLAR - Glabrous. SHEATH - Flat, hyaline white margin. NODE - Short canescent. INTERNODE - Glabrous to short canescent near nodes. ROOTS - Fibrous. CULM - Flat, branched. OUTSTANDING CHARACTERS - Blades and sheath conspicuous white margin, flattened at base. Ligule large acute. Culms branch at nodes. Blade usually folded.

46. *Muhlenbergia curtifolia* Scribn. UTAH MUHLY



Erect, medium sized bunchgrass. VERNATION - Clasped. BLADE - Rolled, semi-erect, pointed; rough, stiff, pubescent ventrally; veins each side of midrib 3-4; ribs prominent dorsally; margin toothed; midrib prominent ventrally; width 1 mm., length 1-2 1/2 cm. AURICLE - None. LIGULE - Membranous, small 1-2 mm., acute-lacerate. COLLAR - Glabrous. SHEATH - Glabrous, veined, round. NODE - Glabrous. INTERNODE - Pubescent to glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Ligule membranous, 1-2 mm., acute-lacerate. Blades rolled, long and narrow. Blade veins 3-4. Plant glabrous.

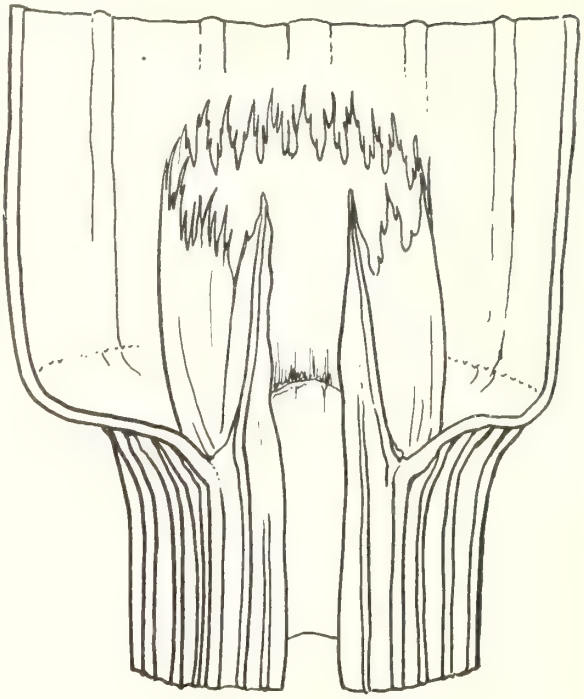
47. *Muhlenbergia emersleyi* Vasey. BULLGRASS

Erect, medium to large bunchgrass. VERNATION - Folded. BLADES - Usually folded, narrow, long; rough dorsally, stiff; veins each side of midrib 3-4; ribs prominent, numerous; margin toothed, midrib prominent, dorsally; width 2-3 mm., length 15-35 cm. AURICLE - None. LIGULE - Membranous, 8-15 mm., acute-lacerate. COLLAR - Glabrous. SHEATH - Glabrous, veined. NODE - Glabrous. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Ligule hyaline, 8-15 mm. acute-lacerate. Blade folded, long, narrow.

48. *Muhlenbergia montana* (Nutt.) Hitchc. MOUNTAIN MUHLY

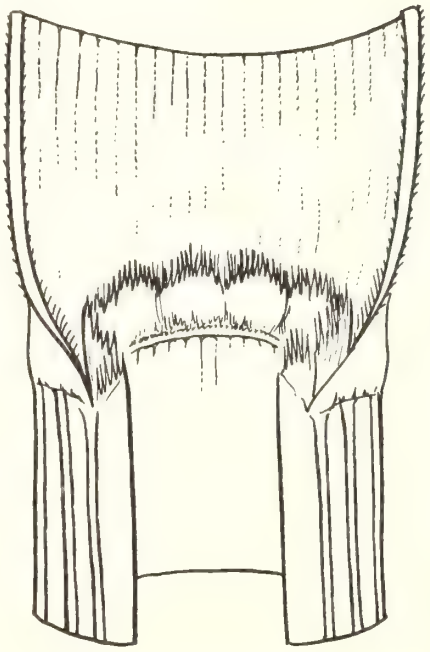
Erect to semi-erect, small bunchgrass. VERNATION - Folded (reported in Colorado as clasped). BLADES - Rolled, narrow, pointed; glabrous and soft; margin toothed; width 1/4-1/2 mm., length 5-20 cm. Mature blades may be flat. AURICLE - None. LIGULE - Membranous, large, 6-12 mm., acute-entire. COLLAR - Distinct, entire. SHEATH - Glabrous, margin light color. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULMS - Round, not branched. OUTSTANDING CHARACTERS - Blade rolled, 5-20 mm., narrow. Ligule long, hyaline, often shredded, 5-8 mm.

49. *Muhlenbergia porteri* Scribn. BUSH MUHLY



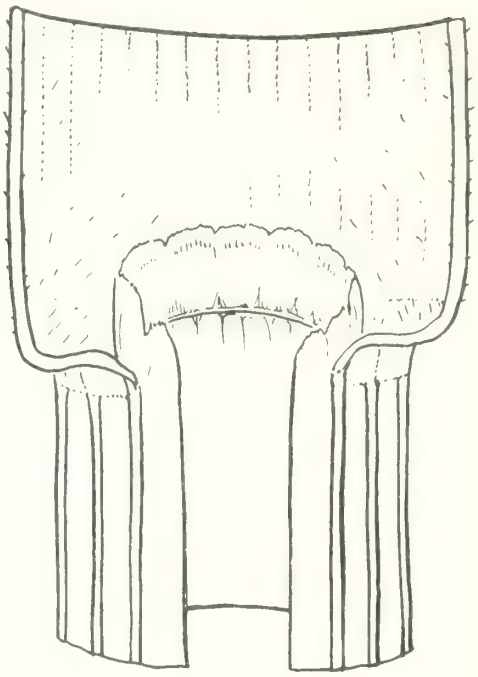
Decumbent, large bunchgrass. VERNATION - Curled. BLADES - Flat, narrow, short, pointed; rough dorsally; veins each side of midrib 2; ribs not prominent; margin toothed, midrib not prominent; width 1 mm., length 3-8 cm. AURICLE - None. LIGULE - Membranous, 1-2 mm., hyaline, truncate-lacerate. COLLAR - Glabrous. SHEATH - Open, glabrous, veined. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Elliptical to round, branched. OUTSTANDING CHARACTERS - Ligule conspicuous, truncate-lacerate, 1-2 mm. Blade short, flat. Branches at nodes. Usually found clambering over shrubs. Culms small, long and semi-woody, persistently green. Florets purple awned.

50. *Muhlenbergia pungens* Thurb. SANDHILL MUHLY



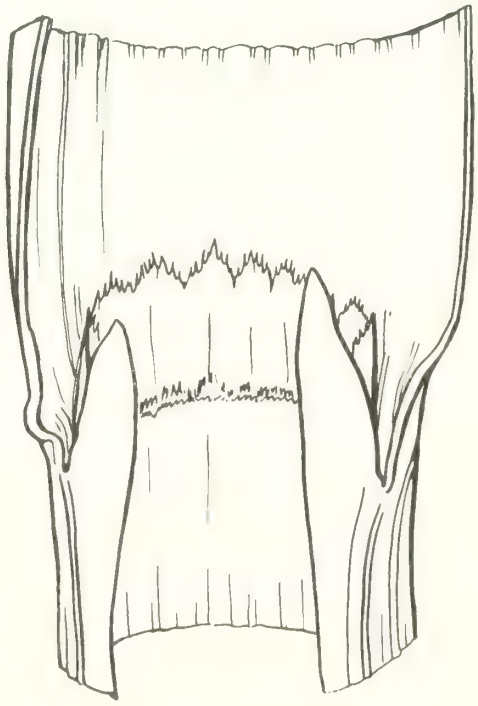
Semi-erect, big bunchgrass. VERNATION - Clasped. BLADES - Rolled, very sharp pointed (pungent); rough ventrally, stiff; ribs indistinct; width 1 mm., length 3-5 cm. AURICLE - None. LIGULE - Membranous, small, 1/2 mm.; truncate-ciliate. COLLAR - Glabrous. SHEATH - Open, glabrous, round, papery margined. NODE - Canescent. INTERNODE - Canescent. ROOTS - Rhizomatous. PANICLE - Reddish-brown. CULM - Round. OUTSTANDING CHARACTERS - Node - internode canescent. Blades rolled pungent. Rhizomatous. Prefers sandy soil. Panicle open, reddish.

51. *Muhlenbergia richardsonis* (Trin.) Rydb. MAT MUHLY



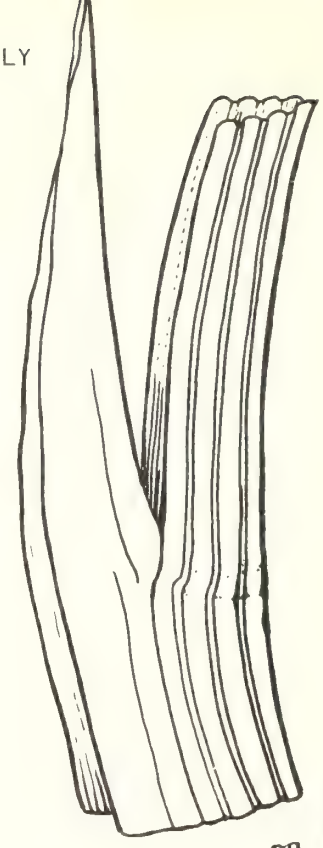
Erect to semi-erect, branched, forming a mat. VERNATION - Folded. BLADES - Rolled, erect, narrow, pointed; glabrous, rough ventrally, stiff; margin toothed; width 1/2 mm., length 1-5 cm. AURICLE - None. LIGULE - Membranous, small 1/2-1 mm., truncate-toothed. COLLAR - Glabrous. SHEATH - Glabrous, white hyaline margin, elliptical. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous, short rhizomes. CULM - Elliptical, branched. OUTSTANDING CHARACTERS - Growth a dense mat. Sheath margin white. Blades short, rolled, erect.

52. *Muhlenbergia rigens* (Benth.) Hitchc. DEERGRASS



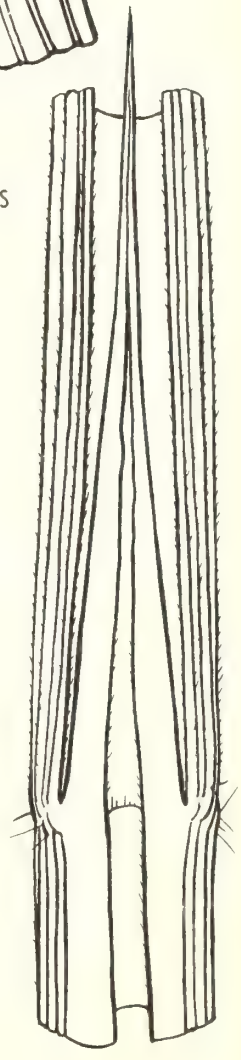
Erect, large bunchgrass. VERNATION - Clasped. BLADES - Flat to rolled, rough, pointed, veins each side of midrib 2; ribs prominent ventrally and dorsally; margin toothed; width 1-2 mm., length 10-20 cm. AURICLE - None. LIGULE - Membranous, 2-4 mm., obtuse-lacerate. COLLAR - Glabrous. SHEATH - White margin, round, glabrous. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Large bunchgrass. Blades long, narrow, rolled to flat. Ligule membranous, large, acute-lacerate, 2-4 mm.

53. *Muhlenbergia torreyi* (Kunth) Hitchc. RING MUHLY



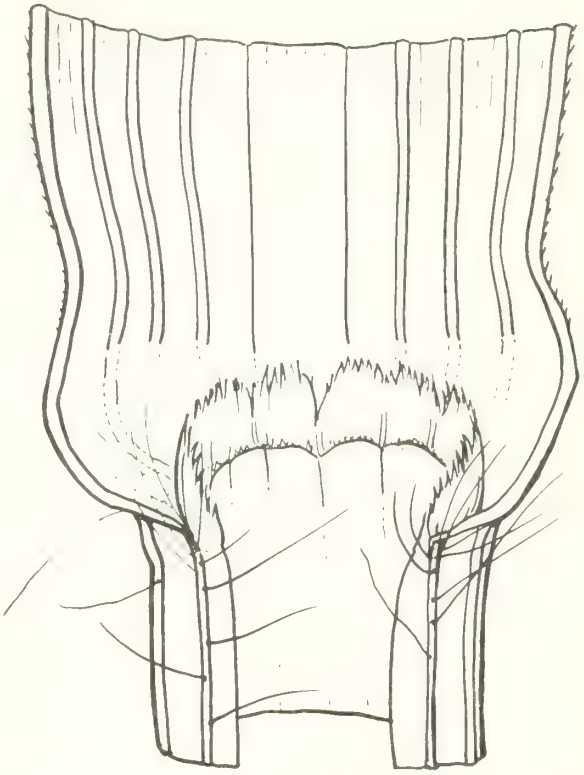
Semi-erect, dense mat, frequently open in center, or ring-like. VERNATION - Folded. BLADES - Small, folded, erect, narrow, pointed; glabrous; midrib not prominent; width 1/2 mm., length 1-2 cm. AURICLE - None. LIGULE - Membranous, medium 2-3 mm.. acute-entire. COLLAR - Glabrous. SHEATH - Glabrous, veined, round. NODE - Canescent. INTERNODE - Canescent. ROOTS - Short rhizomes. CULM - Flat, not branched, very small. OUTSTANDING CHARACTERS - Growth often ring-like, forming a dense mat. Very small blades and stems, flat. Ligule prominent.

54. *Oryzopsis hymenoides* (Roem. & Schult.) Ricker. INDIAN RICEGRASS



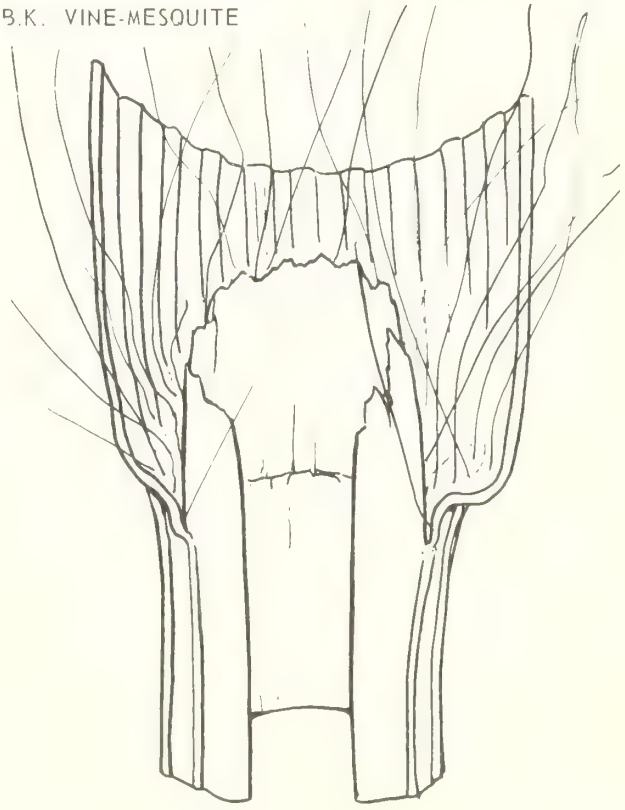
Erect, small bunchgrass. VERNATION - Clasped or curled. BLADES - Rolled, drooping, narrow, pointed; rough dorsally; midrib prominent dorsally; width 1/2 mm., length 5-30 cm. AURICLE - None. LIGULE - Membranous, hyaline 2-3 mm., acute-entire. COLLAR - Glabrous to pubescent. SHEATH - Hairy margin, 1 mm. NODE - Glabrous. INTERNODE - Glabrous to pubescent. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Sheath usually hairy margin. Ligule hyaline, acute-entire. Blade rolled, narrow, long.

55. *Panicum bulbosum* H.B.K. BULB PANICUM



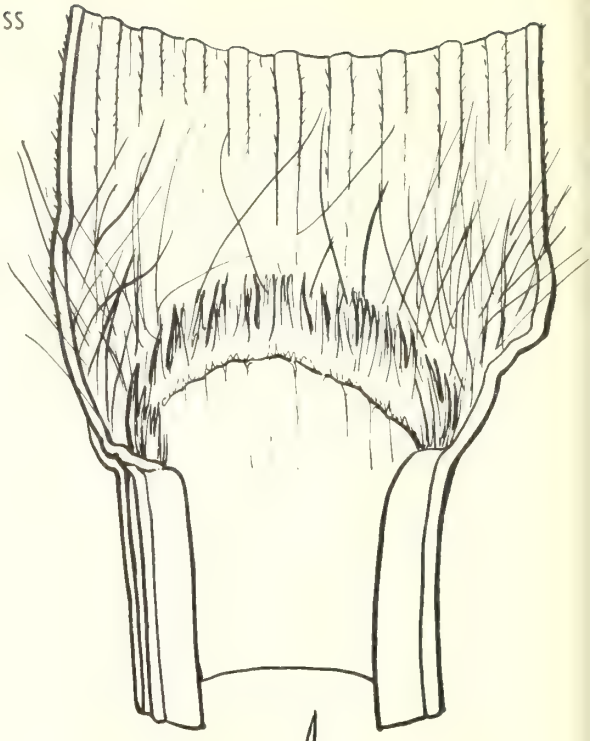
Erect, small bunchgrass. VERNATION - Folded. BLADES - Folded to flat, drooping, narrow, pointed; occasional glandular hairs near ligule; veins each side of midrib 3-4; rib prominent ventrally and dorsally, margin white, midrib prominent dorsally, width 2 mm., length 10-20 cm. AURICLE - None. LIGULE - Membranous, medium 1 mm., truncate-ciliate. COLLAR - Glabrous, divided. SHEATH - Elliptical, occasional glandular hairs near collar. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Corm, rhizomes. CULM - Flat, not branched. OUTSTANDING CHARACTERS - Bulbs prominent. Occasional glandular hairs on blade and sheath.

56. *Panicum obtusum* H.B.K. VINE-MESQUITE



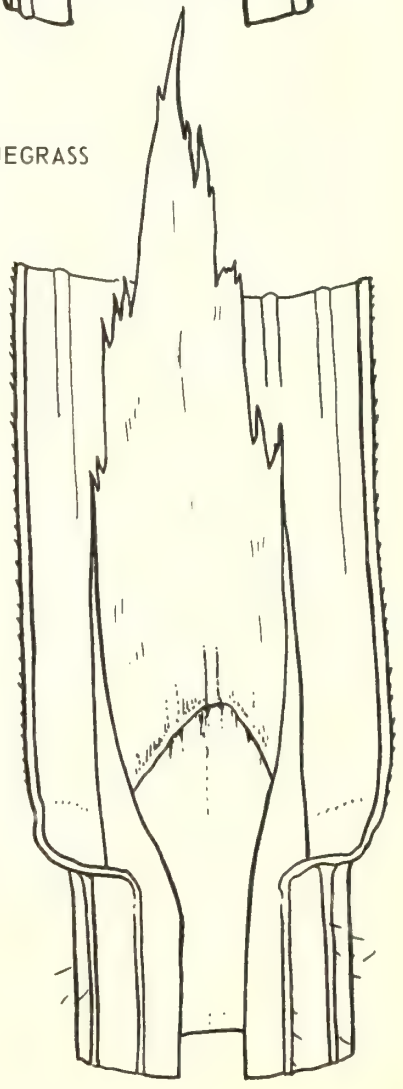
Erect, almost a sod, strongly stoloniferous. VERNATION - Curled. BLADES - Flat, wide, long; glandular hairs ventrally; veins each side of midrib 4; ribs prominent; margin toothed; midrib prominent dorsally; width 4-6 mm., length 10-20 cm. AURICLE - None. LIGULE - Membranous, with occasional hairs 1-3 mm., obtuse-notched. COLLAR - Margin long-hairy. SHEATH - Glandular hairs at base of plant. NODE - Glabrous (Stolons hairy). INTERNODE - Glabrous. ROOTS - Stoloniferous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Blades flat, wide, long, stiff, narrow, pointed. Ligule membranous also long hairs 3-5 mm. Strongly stoloniferous with stolons up to 10 feet long. Sheath with glandular hairs at base of plant.

57. *Pappophorum mucronulatum* Nees. FEATHER PAPPUSGRASS



Erect, large bunchgrass. VERNATION - Curled. BLADES - Flat, drooping, narrow, pointed; rough ventrally, soft; veins each side of midrib 3-4; ribs prominent dorsally; margin toothed; midrib not prominent; width 3-4 mm., length 15-30 cm. AURICLE - None. LIGULE - Membranous, 2-4 mm., bearded, truncate-ciliate. COLLAR - Glabrous. SHEATH - Glabrous, round, paper-like margin. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Round, branched at nodes. OUTSTANDING CHARACTERS - Culms branch at nodes. Ligule membranous 2-4 mm., truncate-ciliate. Blades flat, drooping, narrow, pointed, 15-30 cm. long.

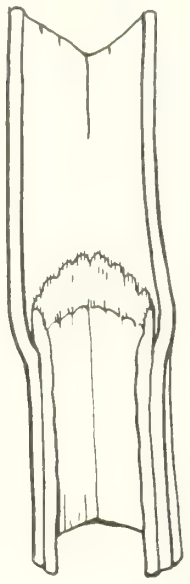
58. *Poa bigelovii* Vasey & Scribn. BIGELOW BLUEGRASS



Erect, small annual bunchgrass. VERNATION - Folded. BLADES - Flat, wide, drooping, narrow, pointed, toothed; glabrous; veins each side of midrib 2; midrib not prominent; margin toothed; ribs not prominent; width 2-4 mm., length 4-12 cm., the tip boat-shaped. AURICLE - None. LIGULE - Membranous, hyaline 2-4 mm., acute-lacerate. COLLAR - Glabrous, divided. SHEATH - Glabrous, margin hyaline. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous, annual. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Annual. Plant glabrous. Ligule hyaline 2-4 mm., acute-lacerate. Blade flat, wide, drooping, long, narrow, pointed.

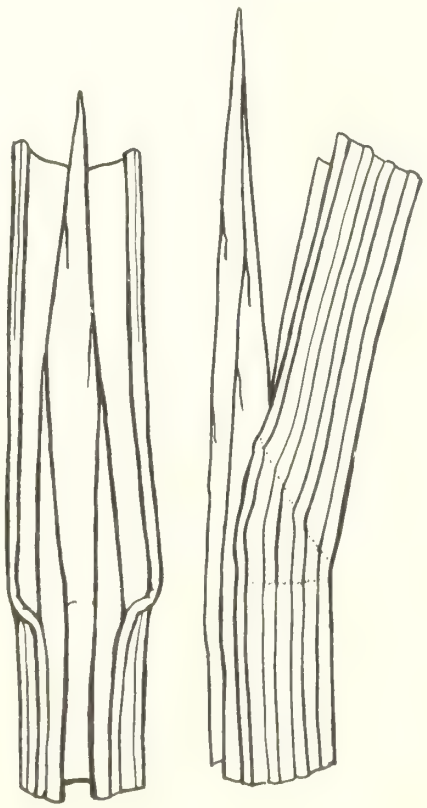
59. *Poa fendleriana* (Steud.) Vasey. MUTTON BLUEGRASS

Erect, small bunchgrass. VERNATION - Folded. BLADES - Folded, erect, glabrous, stiff; ribs dorsal; margin glabrous; width 1/2-1 mm., length 10-20 cm., the tip boat-shaped. AURICLE - None. LIGULE - Membranous, small 1/2 mm. or less, obtuse-toothed. COLLAR - Glabrous. SHEATH - Short canescent to glabrous, elliptical, the margin hyaline. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Elliptical. OUTSTANDING CHARACTERS - Blade long, narrow and folded. Ligule small, obtuse-toothed.

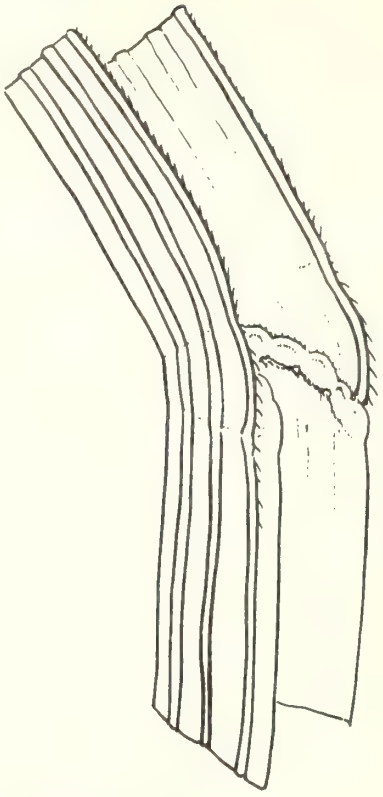


60. *Poa longiligula* Scribn. & Will. LONGTONGUE MUTTON BLUEGRASS

Erect, small bunchgrass. VERNATION - Folded. BLADES - Folded, erect, narrow, pointed; smooth; ribs prominent dorsally; veins indistinct; midrib prominent ventrally; width 1 mm., length 10-20 cm., the tip boat-shaped. AURICLE - None. LIGULE - Membranous, 2-7 mm., acute-lacerate. COLLAR - Glabrous. SHEATH - Glabrous, elliptical. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Blade long, narrow and folded. Ligule prominent, 2-4 mm., acute-lacerate. Blade ribs prominent dorsally.

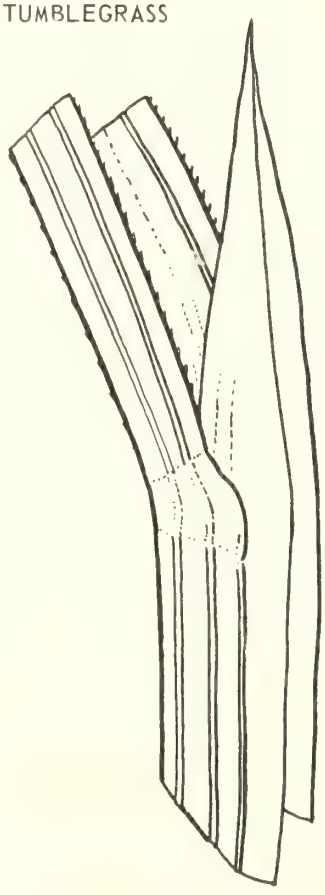


61. *Poa pratensis* L. KENTUCKY BLUEGRASS



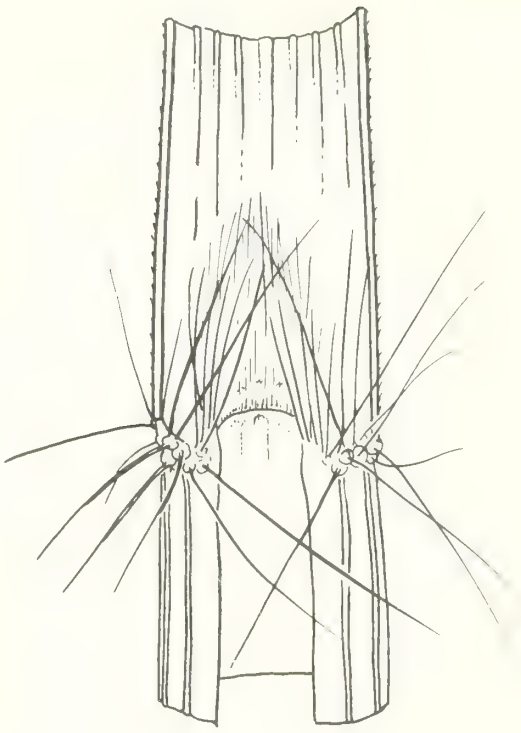
Erect, sodgrass. VERNATION - Folded. BLADES - Folded, soft; ribs prominent ventrally; margin smooth; width 1 mm., length 10-20 cm., the tip boat-shaped. AURICLE - None. LIGULE - Membranous, collar-like, small 1/4-1/2 mm., truncate-entire. COLLAR - Glabrous, not prominent. SHEATH - Glabrous, veined, elliptical, with membranous edges. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Short rhizomes. CULM - Flat, not branched. OUTSTANDING CHARACTERS - Blades long, ribbed, folded. Ligule very small, truncate-entire. Short rhizomes.

62. *Schedonnardus paniculatus* (Nutt.) Trel. TUMBLEGRASS



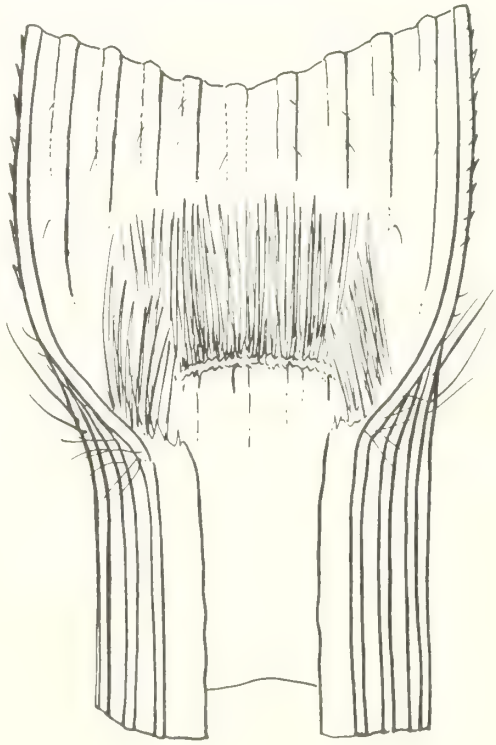
Erect, small bunchgrass. VERNATION - Folded. BLADES - Folded, twisted, erect, narrow, pointed; smooth, soft; veins each side of midvein 1-2; ribs indistinct; margin white, toothed; midrib prominent dorsally; width 1 mm., length 2-3 cm. COLLAR - Smooth. AURICLE - None. LIGULE - Membranous, 2-3 mm., acute-entire. SHEATH - Flat, smooth, veined, paper-like white margined. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Flat, not branched. OUTSTANDING CHARACTERS - Blade and sheath conspicuous white margin. Midrib prominent ventrally. Blade short, twisted. Ligule prominent extending down sheath margin.

63. *Schismus barbatus* (L.) Thell. MEDITERRANEANGRASS



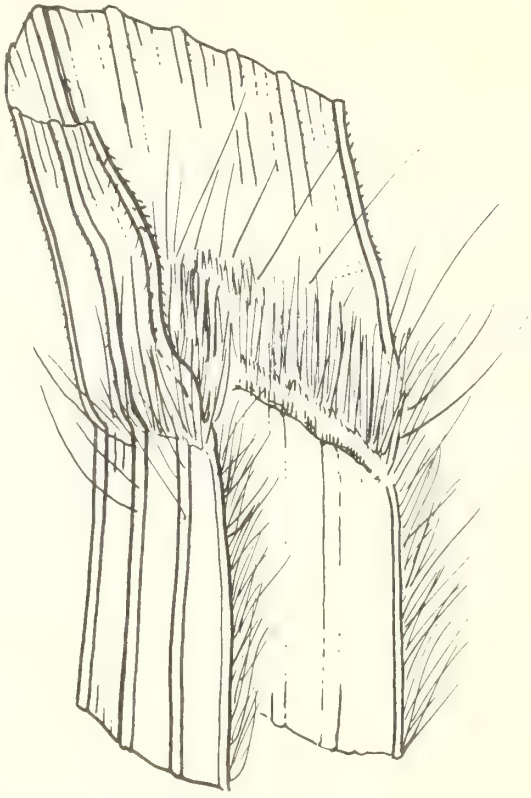
Semidecumbent, small annual bunchgrass. VERNATION - Curled. BLADES - Rolled, narrow, short; hairy ventrally 3-8 mm.; too small to determine veins and ribs; width 1/2-1 mm., length 3-8 cm. AURICLE - None. LIGULE - Hairy, small 1-2 mm. with scattered hairs 3-5 mm. COLLAR - Hairs 1-5 mm. SHEATH - Glabrous, veined, hyaline margin. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous, annual. CULM - Round, not branched. OUTSTANDING CHARACTERS - Annual semidecumbent growth. Long hairs on ligule and collar. Blades rolled, very narrow and short. Roots annual.

64. *Setaria geniculata* (Lam.) Beauv. KNOTROOT BRISTLEGRASS



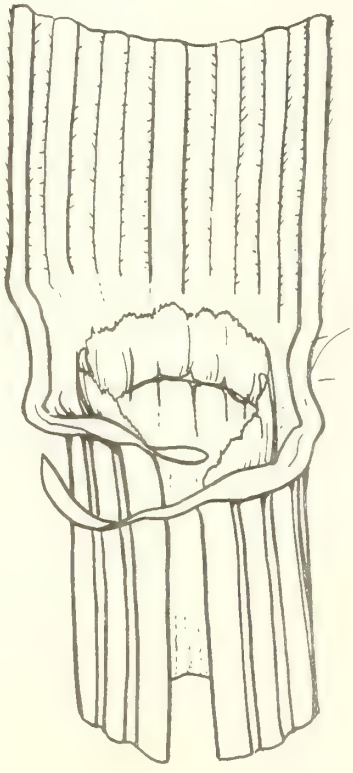
Erect, large bunchgrass. VERNATION - Curled. BLADES - Folded, wide, long, drooping; hairy ventrally near ligule, these occasionally glandular; veins each side of midrib 4; ribs prominent; margin toothed; midrib not prominent; width 3-5 mm., length 10-20 cm. AURICLE - None. LIGULE - Hairy, 1-2 mm., bearded. COLLAR - Hairy. SHEATH - Margin and lower nodes, culm hairy. NODE - Hairy. INTERNODE - Hairy. ROOTS - Fibrous. CULM - Elliptical, branched. OUTSTANDING CHARACTERS - Ligule, node and lower internode hairy. Sheath margin hairy. Collar hairy. Blades folded.

65. *Setaria macrostachya* H.B.K. PLAINS BRISTLEGRASS



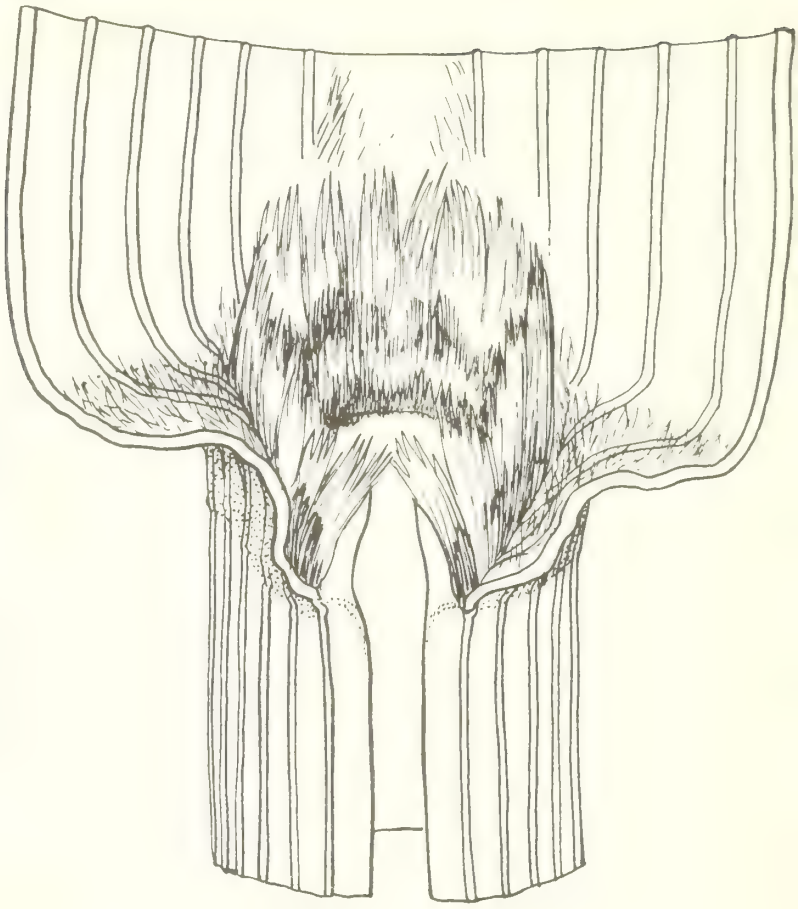
Erect, lower semi-erect, small bunchgrass. VERNATION - Curled. BLADES - Flat, drooping, narrow, long; rough, soft, thin, veins each side of midrib 3-4; ribs prominent with lens; margin light color; midrib prominent ventrally; width 2-3 mm., length 5-20 cm. AURICLE - None. LIGULE - hairy, small 1/2-1 mm. COLLAR - Hairy margin, divided. SHEATH - Occasionally hairy margin. NODE - Glabrous to hairy. INTERNODE - Glabrous to hairy near nodes. ROOTS - Fibrous. CULM - Flat, not branched. OUTSTANDING CHARACTERS - Culms flat. Blade in bud curled. Blade flat, long drooping. Ligule hairy, medium 1-2 mm. Sheath occasional marginal hairs.

66. *Sitanion hystrix* (Nutt.) J. G. Smith. BOTTLEBRUSH SQUIRRELTAIL



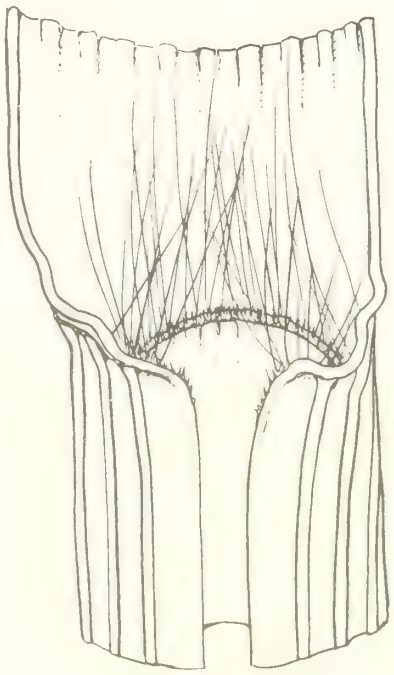
Semi-erect, large bunchgrass. VERNATION - Curled. BLADES - Usually flat, twisted, drooping, narrow, pointed; rough, pubescent to glabrous; veins each side of midrib, 2-4; ribs prominent dorsally; 2-3 mm. wide, 5-20 cm. long. AURICLE - Small 1 mm. LIGULE - Membranous, small 1/4 mm., truncate-entire. COLLAR - Glabrous, divided. SHEATH - Pubescent or glabrous, ribbed, round frequently pinkish. NODES - Glabrous. INTERNODES - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Auricle. Semi-decumbent. Ribs prominent dorsally.

67. *Sorghum halepense* (L.) Pers. JOHNSONGRASS



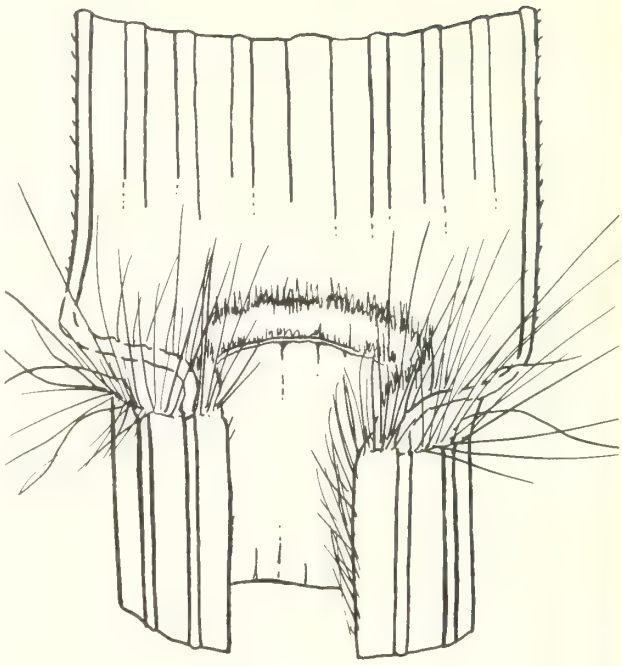
Erect, sod-like. VERNATION - Curled. BLADES - Flat, wide, drooping, narrow, pointed; veins each side of midrib 5-7; ribs indistinct; margin toothed, white; midrib prominent dorsally; width 10-15 mm., length 20-40 cm. AURICLE - None. LIGULE - Hairy, obtuse, 1-2 mm. COLLAR - Pubescent to glabrous. SHEATH - Elliptical, veined. NODE - Glabrous to very short canescent. INTERNODE - Glabrous. ROOTS - Rootstalk rhizomatous. CULM - Elliptical, occasionally branched. OUTSTANDING CHARACTERS - Massive rootstalks rhizomes. Blade margin white. Blades large, flat. Prefers wet areas, roadside, irrigation ditches.

68. *Sporobolus airoides* Torr. ALKALI SACATON



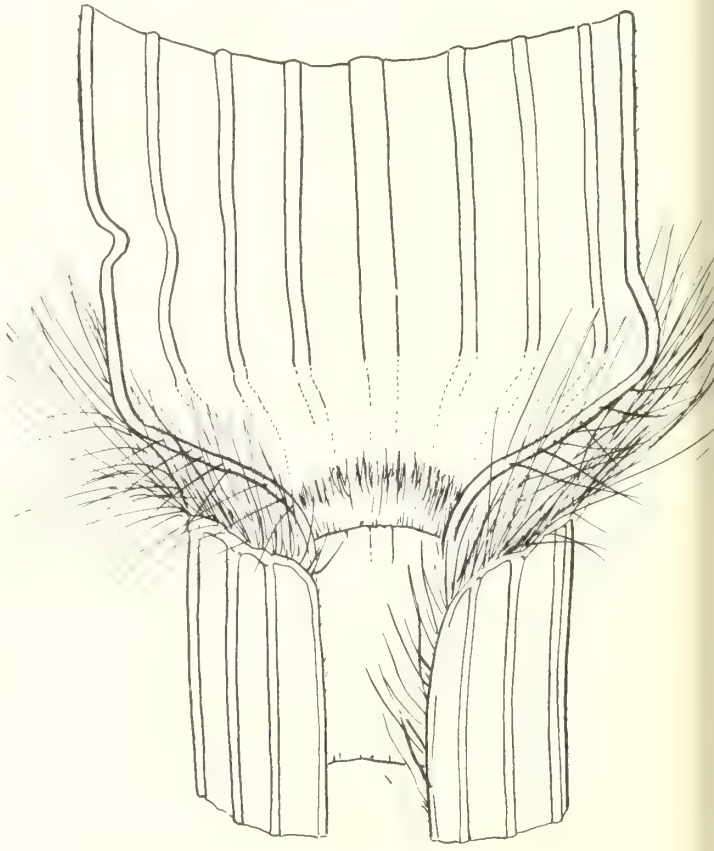
Erect, large bunchgrass. VERNATION - Curled. BLADES - Rolled, drooping, narrow, pointed; glabrous, veins each side of midrib 3-4; ribs indistinct; margin glabrous; midrib not prominent; width 1 mm., length 10-25 cm. AURICLE - None. LIGULE - Hairy, 1/2-1/4 mm., hairs on back of ligule 1-3 mm. COLLAR - Pubescent margin, divided. SHEATH - Round, glabrous, papery margin. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Short rhizomes. CULM - Round, not branched. OUTSTANDING CHARACTERS - Blade narrow, long, rolled. Ligule hairy, small 1/4-1/2 mm., long hairs at back 1-3 mm. Large bunches 1-2 feet when mature.

69. *Sporobolus asper* (Michx.) Kunth. TALL DROPSEED



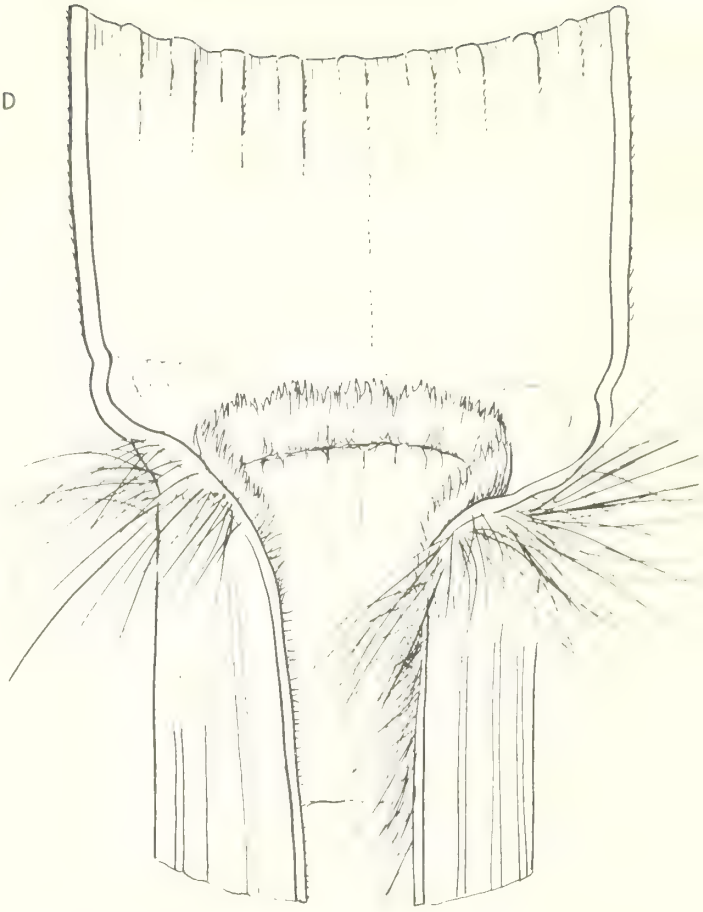
Erect, medium bunchgrass. VERNATION - Curled (sometimes reported as clasping). BLADES - Usually flat, narrow, pointed; glabrous, rough ventrally, soft; veins each side of midrib 2-3; margin toothed; ribs prominent ventrally and dorsally; width 2-3 mm., length 5-20 cm. AURICLE - None. LIGULE - Hairy, short. COLLAR - Tufted. SHEATH - Hairy margin 2-3 mm., usually pinkish at base. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Round, frequently branched at node. OUTSTANDING CHARACTERS - Blade flat, glabrous. Collar tufted. Sheath occasionally with marginal hairs. Panicles included well in sheath. Culm usually branched. In Arizona known only from Apache County.

70. *Sporobolus cryptandrus* (Torr.) A. Gray. SAND DROPSEED



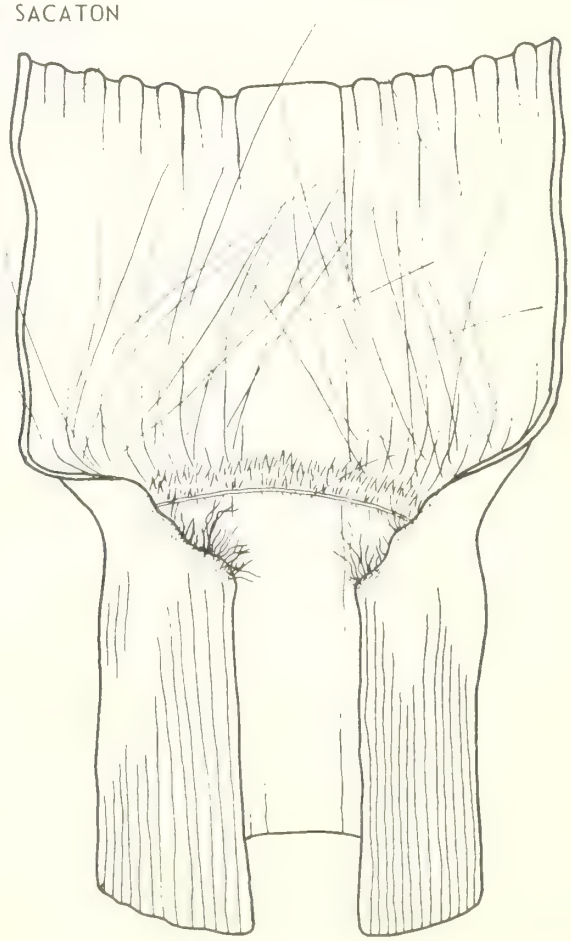
Erect, medium bunchgrass. VERNATION - Curled. BLADES - Flat, wide, long; glabrous; veins each side of midrib 3-4; ribs prominent; margin toothed; midrib not prominent; width 3-8 mm., length 15-20 cm. AURICLE - None. LIGULE - Hairy, hairs 2-3 mm. on margin. COLLAR - Conspicuous tufts of hair on margin, 2-3 mm. SHEATH - Hairy often on one margin, the panicle more or less covered by the sheath. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Blades flat, long. Panicle included in sheath. Ligule and collar bearded. Culms not branched. Almost throughout the state, 150-7,000 feet elevation.

71. *Sporobolus giganteus* Nash. GIANT DROPSEED



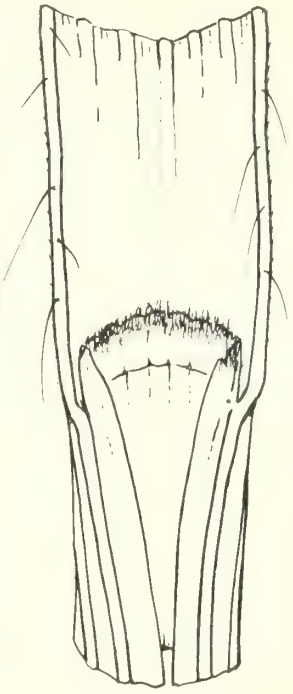
Erect, large bunchgrass. VERNATION - Curled. BLADES - Flat to rolled, erect; rough ventrally, stiff; veins each side of midrib 3-4; ribs prominent dorsally; margin toothed; midrib not prominent; width 2-8 mm., length 15-35 cm. AURICLE - None. LIGULE - Hairy, short, 1/2 mm. COLLAR - Glabrous, margins tufted, distinct. SHEATH - Round, one margin usually hairy, veined. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Round, not branched. OUTSTANDING CHARACTERS - Ligule large, hyaline, 6-12 mm., acute. Blade long, usually rolled. Large bunchgrass.

72. *Sporobolus wrightii* Munro. SACATON



Erect, large bunchgrass. VERNATION - Curled. BLADES - Flat, drooping, long, narrow, pointed; glabrous; veins each side of midrib 3; ribs prominent ventrally; margin toothed; midrib prominent ventrally; width 3-6 mm., length 45-60 cm. AURICLE - None. LIGULE - Hairy small, 1/2 mm., obtuse-lacerate. COLLAR - Glabrous. SHEATH - Glabrous, veined, round. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Round. OUTSTANDING CHARACTERS - Blades flat, long, wide. Ligule short, hairy. Large coarse bunchgrass.

73. *Stipa neomexicana* (Thurb.) Scribn. NEW MEXICAN FEATHERGRASS

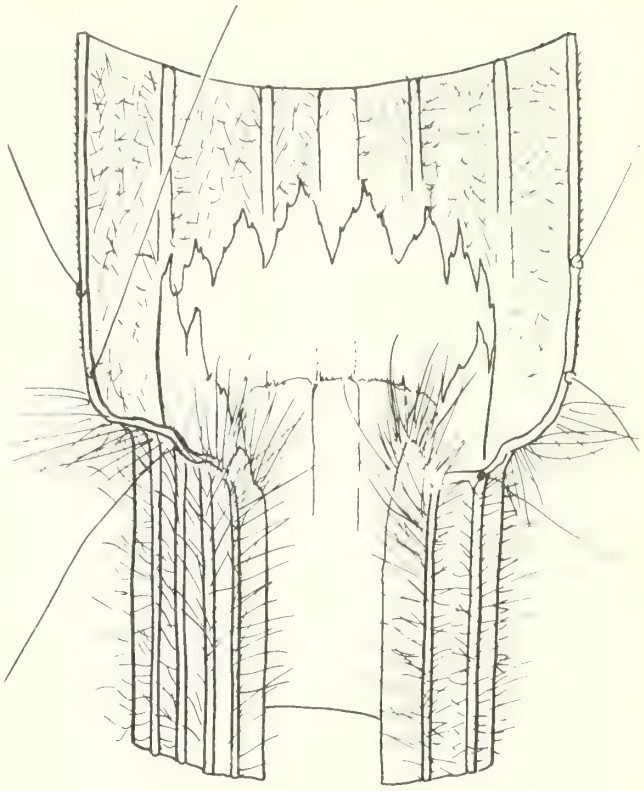


Erect, medium bunchgrass. VERNATION - Folded (reported as curled in Colorado). BLADES - Rolled, drooping, narrow, pointed; glabrous; veins indistinct; midrib not prominent; width 1/2-1 mm., length 25-35 cm. AURICLE - None. LIGULE - Membranous, very small 1/4 mm., truncate-ciliate. COLLAR - Glabrous, margin appearing hairy, divided, indistinct. SHEATH - Elliptical, veined. NODE - Glabrous. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Blades long, needle-like. Ligule very small, 1/4 mm., truncate-ciliate. Awns long, twisted with long hairs toward tip.

74. *Stipa pringlei* Scribn. PRINGLE NEEDLEGRASS

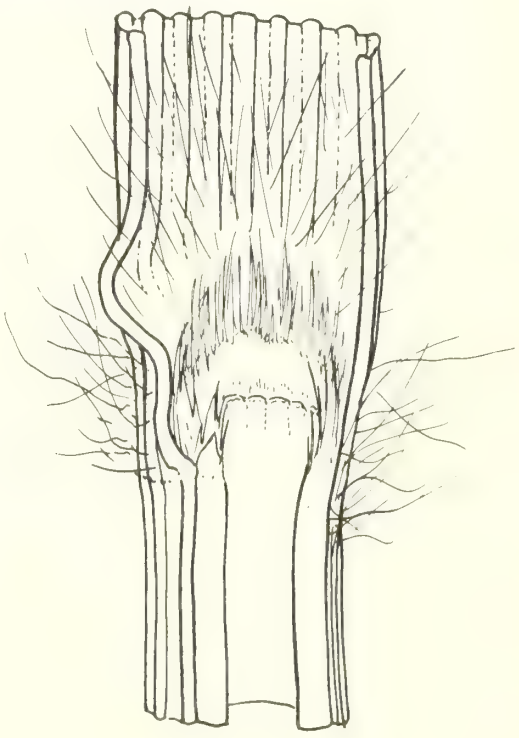
Erect, small bunchgrass. VERNATION - Curled. BLADES - Flat, drooping, narrow, pointed; rough ventrally; veins each side of midrib 2; ribs prominent ventrally and dorsally; margin toothed; midrib prominent ventrally; width 2 mm., length 20-30 cm. AURICLE - None. LIGULE - Membranous, small 1-2 mm., obtuse-lacerate. COLLAR - Glabrous. SHEATH - Elliptical, veined, margin hyaline. NODE - Usually pubescent. INTERNODE - Glabrous to short canescent near nodes. ROOTS - Fibrous. CULM - Elliptical, not branched. OUTSTANDING CHARACTERS - Blades flat, narrow, long. Ligule membranous, small 1-2 mm., obtuse-lacerate. Awns twisted 1-3 cm.

75. *Trichachne californica* (Benth.) Chase. ARIZONA COTTONTOP



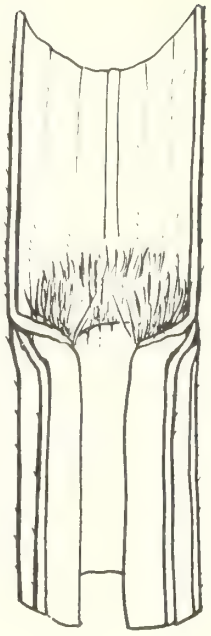
Erect, large bunchgrass. VERNATION - Curled. BLADES - Flat, drooping, narrow, pointed; glabrous or pubescent ventrally and dorsally, occasional glandular hairs dorsally; veins each side of midrib 3; ribs prominent ventrally; margin toothed, white; midrib prominent; width 3-4 mm., length 8-12 cm. AURICLE - None. LIGULE - Membranous, 2-3 mm., obtuse-lacerate. COLLAR - Hairy ventrally, entire. SHEATH - Glabrous or pubescent, elliptical, margin hairy. NODE - Pubescent, occasionally glabrate. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Elliptical, branched. OUTSTANDING CHARACTERS - Blade margin white. Blades flat, long. Culms branched. Ligule 2-3 mm., obtuse-lacerate.

76. *Tridens muticus* (Torr.) Nash. SLIM TRIDENS



Erect, small bunchgrass. VERNATION - Curled. BLADES - Rolled, erect, narrow, pointed; with occasional glandular hairs dorsally; scabrous; midrib prominent dorsally; veins each side midvein 4-5; width 2-4 mm., length 8-20 cm. AURICLE - None. LIGULE - Hairy, small 1/2-1 mm. COLLAR - Hairy. SHEATH - Open, hairy on margin, round. NODE - Pubescent. INTERNODE - Glabrous. ROOTS - Fibrous. CULM - Round. OUTSTANDING CHARACTERS - Blade usually rolled. Ligule hairy and small. Node pubescent.

77. *Tridens pulchellus* (H.B.K.) Hitchc. FLUFFGRASS



Erect, small bunchgrass. VERNATION - Folded. BLADES - Rolled, erect, very small, narrow, pointed; rough ventrally; ribs distinct, veins indistinct; margin toothed; width 1/4 mm., length 2-5 cm. AURICLE - None. LIGULE - Hairy, small 1/2 mm. COLLAR - Smooth, small, entire. SHEATH - Margin paper-like, the lower long ciliate. NODE - Glabrous, roots at nodes. INTERNODE - Glabrous to pubescent. ROOTS - Fibrous. CULM - Elliptical, terminal node branched with cluster of flowers often cobwebby. OUTSTANDING CHARACTERS - Blades ribbed, rolled, small and short. Sheath margin conspicuously paper-like, long ciliate. Flowers clustered, somewhat exceeded by the leaves, cobwebby. Roots at nodes.

GLOSSARY

ACUTE: Terminating sharply in an angle of less than 90°.

AURICLE: Small, membranous, claw-like extension of the collar of some grasses.

AWN: A needle-like extension of the grass floret, as in Stipa (needlegrass) or Aristida (three-awn).

CANESCENT: Grayish or whitish due to dense, fine hairs.

CILIATE: Fringed with hairs on the edge.

COLLAR: The region on the outer side of the grass leaf at the junction of the sheath and blade.

CORM: A swollen or enlarged, rounded, solid, fleshy, mostly subterranean, stem base. Like a bulb in shape and appearance, except that it is solid instead of being composed of fleshy scales.

CULM: The jointed stalk or stem of grasses, usually hollow except at the nodes, and mostly herbaceous.

DECUMBENT: Reclining on the ground but with the end ascending, bending horizontally at the base. Said of stems. Decumbent conveys the idea of weakness.

DIVIDED: Refers to the shape of the collar on the back of the sheath.

DORSAL: Refers to the top of the blade, opposite to ventral.

ELLIPTICAL: The cross section of the stem partially flattened.

ENTIRE: With an even margin, without teeth or lobes.

FIBROUS: Refers to a mass of thread-like roots.

FLORET: A unit of the spikelet of a grass inflorescence, consisting usually of lemma, palea, stamens, and pistil.

GENICULATE: Knee-like; bent like a knee; said of stems and awns of needlegrass (Stipa).

GLABRATE: Becoming glabrous or nearly so in age.

GLABROUS: Devoid of hairs or pubescence; smooth in the sense of absence of all hairiness.

GLANDULAR: Pertaining to or possessing glands at the base of hairs.

GLOSSY: Smooth, shining.

HIRSUTE: Hairy with rather coarse, stiffish, straight, beard-like hairs.

HISPID: Bristly; beset with stiff, rough, bristle-like hairs.

HYALINE: Thin and translucent.

INFLORESCENCE: The flowering portion of a grass plant, consisting of spikelets and florets.

INTERNODE: The portions of a stem between the nodes, or joints.

INVOLUTE: Inrolled; i.e. with both edges rolled in toward the middle (blade) each edge presenting a spiral appearance in cross-section.

LACERATE: Deeply and irregularly cut along the edges.

LANCEOLATE: Lance-shaped; several times longer than broad, and tapering from the relatively narrow base to apex.

LIGULE: The projecting, usually tongue-like, membranous end of the lining of the leaf sheath, seen at the base of the leaf, between it and the stalk, and a very characteristic feature of the grass family. The ligule is quite often an important means of distinguishing grasses; sometimes it is reduced to a mere fringe of hairs or to a hardened ring.

MAT: Growing thickly, or closely interwoven.

MIDRIB: The central or main rib common in blades of grasses.

NODE: A joint or knot. Said especially of stems, whose nodes or joints are enlarged, often dark colored, and are the points whence leaves and additional flowers often spring.

NOTCHED: An edge with teeth or lobes.

OBTUSE: Blunt or rounded at the tip; not sharply pointed.

PANICLE: An open inflorescence in which the lower branches are typically longer and blossom earlier than the upper branches.

PERENNIAL: Lasting for three or more years; said especially of herbaceous plants that are neither annual nor biennial.

PILOSE: Hairy with soft, slender hairs.

PLUMED: Feather-like, having fine hairs on either side as the awn of certain Stipa species.

PUBESCENT: Clothed with soft hairs or down.

PUNGENT: Sharply and rigidly pointed.

RACEME: A simple, elongated, indeterminate flower cluster.

RACHIS: The axis of a spike, raceme, or branch of a panicle; the organ that supports the florets.

RETRORSE: Directed back or downward, as hairs on the sheath of certain grasses.

RHIZOME: An underground stem; recognized by the regular nodes and internodes; e.g. Sorghum halepense.

RIB: The primary veins of a blade.

RUDIMENTARY: Reduced.

RUNNER: A long, slender form of creeping branch, prostrate on the ground. Each runner, after having grown to its full length, strikes root from the tip (it sometimes roots at the joints also, in

which case it may merge into a stolon), fixing the tip to the ground, then forms a bud at that point, which later develops into a tuft of leaves and so gives rise to a new plant.

SCABROUS: Rough or harsh to the touch.

SCALLOPED: Margin of a blade that buckles, resulting in waves.

SHEATH: In grasses, the lower part of the leaf which envelops the stem or culm.

SHREDDED: Deeply and irregularly cut along the edges.

SOD: A group of plants growing densely together forming a solid mat, as buffalograss or Kentucky bluegrass grown for lawns.

SOLID: Applied to the culm, which is solid in a few grasses and all sedges and rushes.

SPIKELET: In grasses, the name applied to the cluster of one or more florets.

STOLON: A trailing or reclining branch, above ground, which takes root where it touches the soil, there sending up new shoots which later become separate plants.

TOOTHED: An edge with regular notches.

TRUNCATE: Squared at the tip; terminating abruptly as if cut off crosswise.

VEIN: One of the fibrovascular bundles forming part of the framework (skeleton) of a leaf; more or less parallel veinations (as in a grass blade).

VENTRAL: Refers to the inner surface of the blade, facing the culm as the leaf is held erect.

VILLOUS: Densely hairy with long, soft hairs.

WOOLLY: Covered with long, matted hairs.

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Copple, R. F., and Pase, C. P.
1967. A vegetative key to some common Arizona range grasses.
U. S. Forest Serv. Res. Paper RM-27, 72 pp., illus.

Seventy-seven common Arizona range grasses are included in this vegetative key. A shortcut key also assists in rapid identification. In a separate section, grasses are grouped according to major vegetative characters. A sketch of the ligule and collar area of each species provides an easy means of comparison with certain key characters. A detailed description of the vegetative characters of each species provides a final check on identification.

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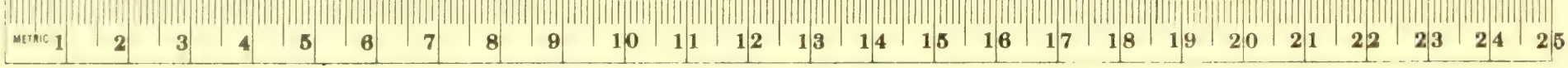

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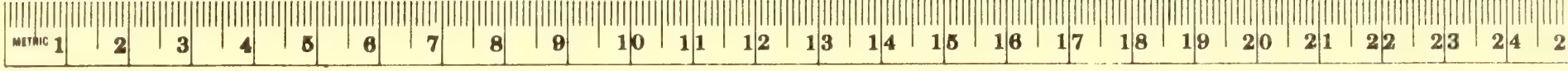
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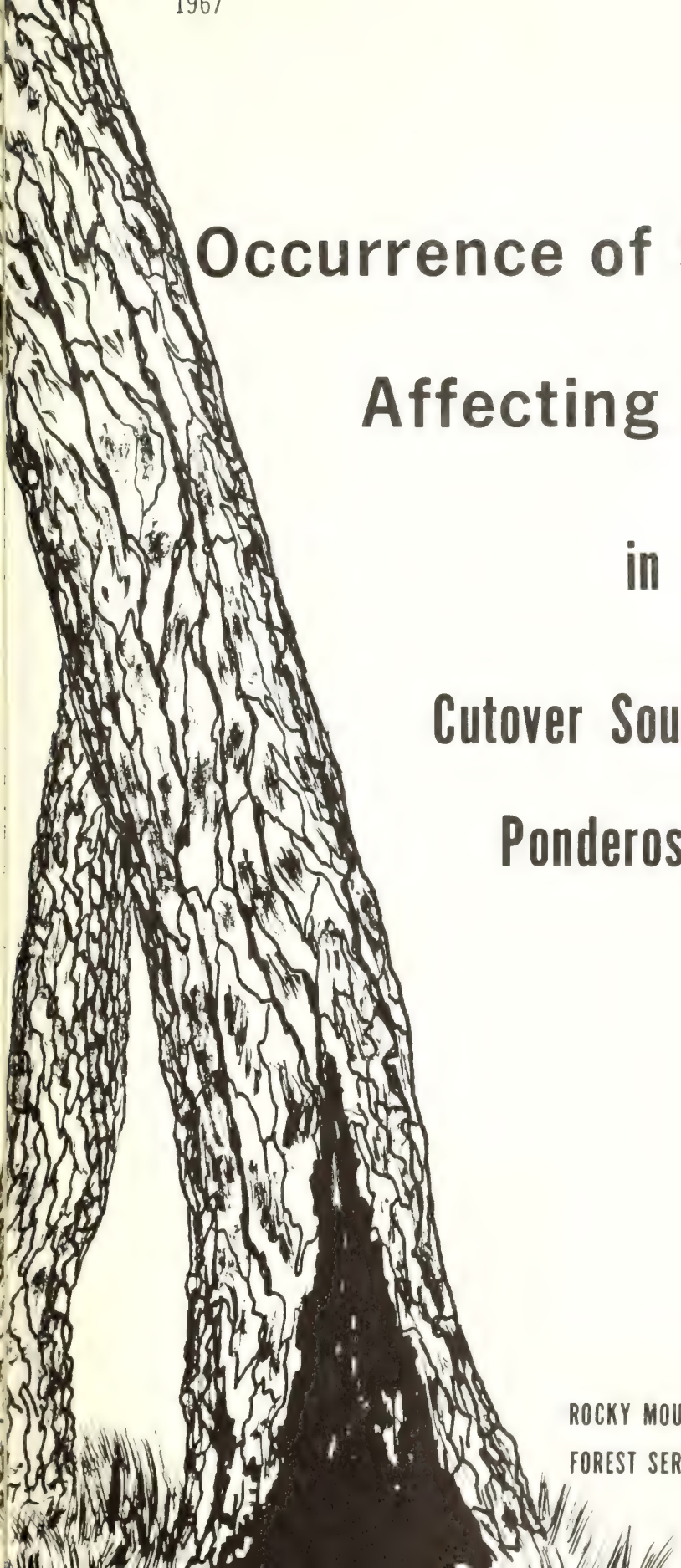
1967

U.S. Forest Service
Research Paper RM-28



Occurrence of Stem Features Affecting Quality in Cutover Southwestern Ponderosa Pine

Peter F. Ffolliott
Roland L. Barger

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

The basic inventory method employed in this study, and analysis of typical stem-quality information obtained, are discussed in detail in U.S. Forest Service Research Paper RM-15, "A Method of Evaluating Multiproduct Potential in Standing Timber," available from the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

U. S. Forest Service Research Paper RM-28 1967

OCCURRENCE OF STEM FEATURES AFFECTING QUALITY IN CUTOVER SOUTHWESTERN PONDEROSA PINE

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Occurrence of Stem Features Affecting Quality in Cutover Southwestern Ponderosa Pine

by

Peter F. Ffolliott and Roland L. Barger

Better information is needed about physical stem characteristics that affect the quality of standing timber. Stem quality for most primary products is largely determined by the same few stem features--features such as sweep, crook, fork, scar, and aggregate knot or limbing characteristics. Given sufficient information about the occurrence and severity of these characteristics, we can readily estimate suitability of the timber for a wide variety of products. Concurrently, we need adequate methods of observing, measuring, and expressing the quality of standing timber.

This paper reports the results of a study designed to determine the frequency of occurrence of particular stem-quality features in cutover ponderosa pine stands (Pinus ponderosa Laws.). Specific objectives of the study were to (1) test the application of recently developed methods of timber-quality inventory and classification; and (2) determine the current occurrence and severity of stem-quality characteristics in cutover stands. The quality information developed provides a basis for appraising stand potential for a variety of products. It also provides a basis from which to determine stand-quality changes over time. The methods employed could be applied in other timber types to provide similar timber-quality information.

Basic Timber Quality Information Needed

Patterns of forest utilization in the Southwest are changing. The industry, historically oriented toward lumber production alone, is adopting new products, new conversion methods, and more diversified operations. Because the "sawtimber" tree of a decade ago may now be actively considered for products other than lumber, broader concepts of timber quality are required. The character of the timber is also changing as high-quality, old-growth timber is removed and harvesting operations re-enter previously logged stands.

The bulk of the future regional timber resource is contained in stands of cutover ponderosa pine (fig. 1). Interest in product diversification and increasing dependence

Figure 1.--ponderosa pine, such as the one pictured, contain a large proportion of the regional timber resource.

upon cutover stands both emphasize the need for better knowledge of these stands. They must be described in terms of suitability for a range of potential primary products. Determining the occurrence of stem-quality features related to suitability and/or yield for particular products is a necessary initial step.

Cutover Ponderosa Pine Area Studied

Sawtimber has been harvested one or more times from much of the ponderosa pine type in the Southwest, leaving extensive cutover stands. Previous harvest cuts have generally removed from 35 to 60 percent of the merchantable sawtimber volume. The study was concerned with the stem quality of the sawtimber currently stocking these cutover stands.

The area studied (fig. 2) consists of 11 pilot watersheds encompassing approximately 9,000 acres on the Beaver Creek Watershed Evaluation Project in north-central Arizona (Worley 1965).[2] The pine stands covering the area are uneven-aged, with much of the stand arranged in even-aged groups. Site index for the area ranges from 50 to 70 feet at 100 years of age (Meyer 1938). Gambel oak (Quercus gambelii Nutt.) and alligator juniper (Juniperus deppeana Steud.) occur as intermingling minor species. Timber was last harvested from the area during the period 1943-50, when half of the merchantable volume of sawtimber was removed. Current sawtimber volume on the area averages 4,000 board feet per acre (Myers 1963).

Measuring Stem Quality Characteristics

Field data were obtained during the development of a method of observing and recording visual stem-quality features in standing timber (Ffolliott and Barger 1965). The inventory method was designed to provide for systematic observation and measurement of all major visual stem characteristics related to product quality. When coupled with valid sampling techniques, the method allows computation of the frequency of occurrence of observed features.

Point-sampling techniques were used to select sample trees. A total of 1,403 permanent sample points were located on the pilot watersheds by means of a systematic sampling design with multiple random starts (Freese 1962, Shiue 1960). Ponderosa pine trees 7.0 inches and larger in diameter were selected at each sample point with an angle gage corresponding to a basal area factor of 25. A total of 3,799 sample trees were so selected for observation and measurement. For each sample tree, visual stem-quality features that might affect product quality and yield were recorded. The stem-quality features specifically observed and measured included (1) stem form features of sweep, crook, fork, and lean; (2) injury or scar features; and (3) log knot configurations in sawtimber stems. The procedure for measuring, classifying, and recording each of these stem features is outlined below:

I. Stem form features:

A. Sweep, recorded as
   1. Minor--less than 1/3 d.b.h. deviation in straightness.
   2. Major--1/3 d.b.h. or more deviation in straightness.

B. Crook, recorded as
   1. Minor--less than 1/2 mean diameter deviation in straightness within a section 5 feet or less in length.
   2. Major--1/2 mean diameter or more deviation in straightness within a section 5 feet or less in length.
   3. Location of crook in stem, to nearest half log.

C. Lean, recorded as degree of lean, to nearest 5°.

D. Fork, recorded as location of fork in stem, to nearest half log.

[2] *Names and dates in parentheses refer to Literature Cited, p. 11.*

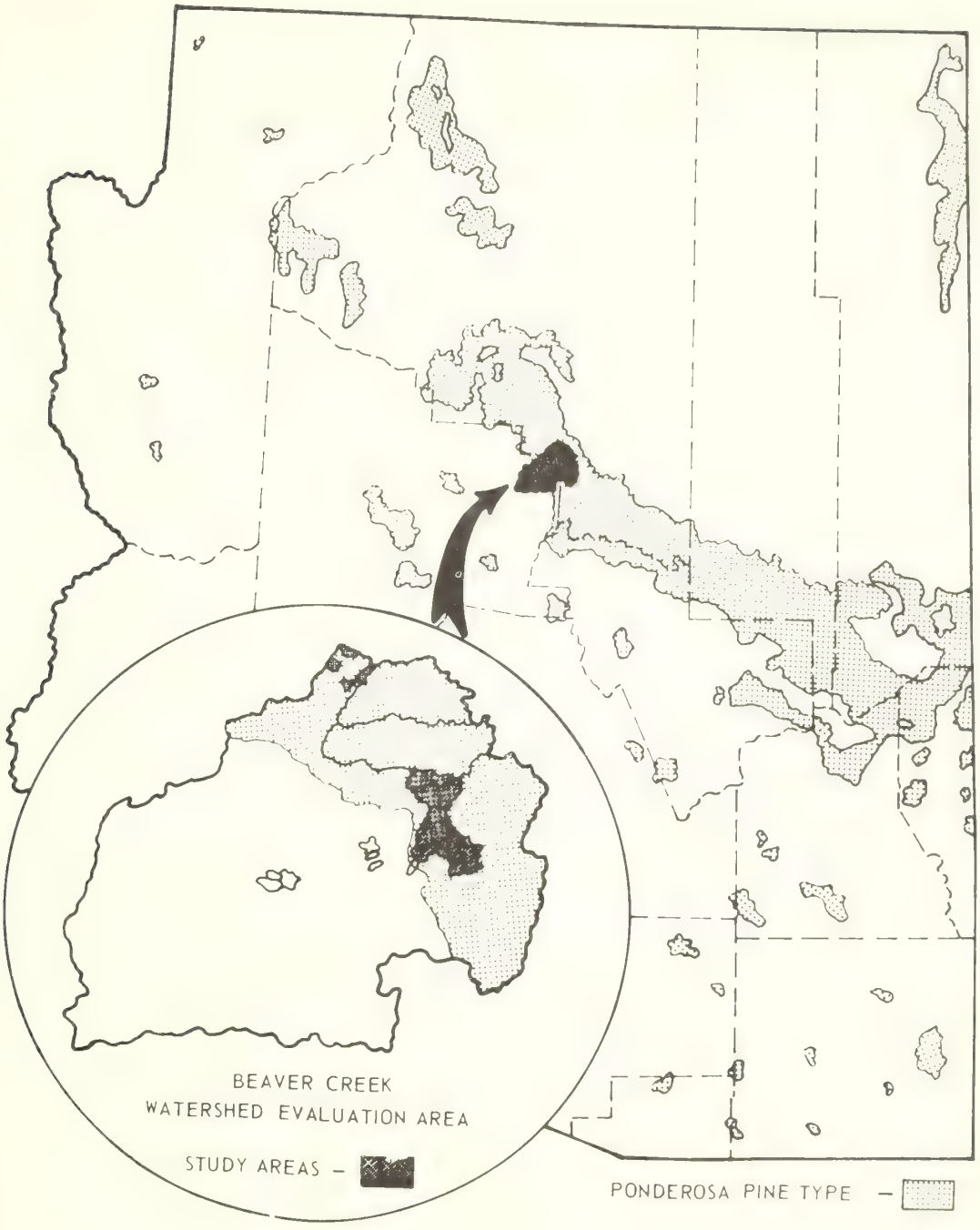

Figure 2.--The study areas, part of the [illegible], are located within the major belt of ponderosa pine timber extending across Arizona.

II. Injury features:

A. Basal scar, recorded as
1. Minor--less than 1/4 bole circumference affected.
2. Major--1/4 or more of bole circumference affected.

B. Lightning scar, recorded as
1. Minor--less than 1/4 bole circumference affected.
2. Major--1/4 or more of bole circumference affected.

C. Damaged top, recorded as
1. Dead top.
2. Broken top.

III. Log knot configurations:

Both occurrence and distribution of log knots are important indicators of product potential. Accordingly, the knot features of all sample trees 11.0 inches and larger in diameter were characterized in two ways: (1) presence of clear surface area in the first two 16-foot logs; and (2) number and size of knots in first 16-foot log. Specific information recorded includes:

A. Clear 8-foot faces (panels 8 feet by 1/4 bole circumference), recorded by position within each succeeding 8-foot stem section, to 32 feet height or to a 10-inch top diameter.

B. Log knots and knot indicators, recorded as
1. Number of knots in each full face of first 16-foot log.
2. Diameter of largest knot in each log face, to nearest inch.
3. Condition of largest knot in each log face (live or dead).

Stem-quality information for all sample trees on the study area was aggregated by tree diameter class. A base stand table representative of the study area was developed from data for all inventoried trees. Separate stand tables were then developed for trees exhibiting each observed quality characteristic. These tables, when expressed as a proportion of the base stand table, indicated the frequency of occurrence of the represented feature. A frequency-of-occurrence table was thus constructed for each observed quality feature, which indicated the frequency of occurrence within each size class of trees and within the stand as a whole.

Log knots and clear surface area are usually common to all stems; consequently, the stand table method of expressing occurrence is not adequate. The occurrence of these features was expressed instead as proportion of stems having specified knot or clear face characteristics.

Occurrence of Stem Quality Features

The inventory documented the occurrence and severity of stem characteristics related to quality in the cutover stands sampled. Aggregate occurrence data provided a basis for calculating frequency with which each characteristic occurs within size classes and within the stand. To facilitate presentation, the frequency tables for individual stem features have been converted to bar graphs, and tree diameter classes have been grouped into these four major size classes:

Size class	Diameter range (Inches)	Sample trees (Number)
Poles	7.0-10.9	1,436
Small sawtimber	11.0-16.9	1,150
Medium sawtimber	17.0-22.9	559
Large sawtimber	23.0+	634

Stem Form Features

Irregular form features in the merchantable stems of standing timber substantially influence product potential. Form is more important than volume in determining the value of stands for some products. Sweep, crook, lean, and fork are particularly important (Pearson 1950). Sweep and crook may substantially lower the net volume in a merchantable stem, and may be inadmissible defects in such products as commercial poles. Lean, a common characteristic of ponderosa pine, is an important form feature because of

the associated formation of compression wood (Pillow and Luxford 1937). Forking in the merchantable stem limits the length and net volume of products obtainable. The distorted grain accompanying a fork may also lower the quality of adjacent material (Jackson 1962).

The occurrence of sweep, crook, lean, and fork in ponderosa pine trees on the study area is illustrated in figures 3, 4, 5, and 6, respectively.

Injury Features

Mechanical injuries such as scars can reduce substantially the usable volume of standing timber. Injury scars are also commonly

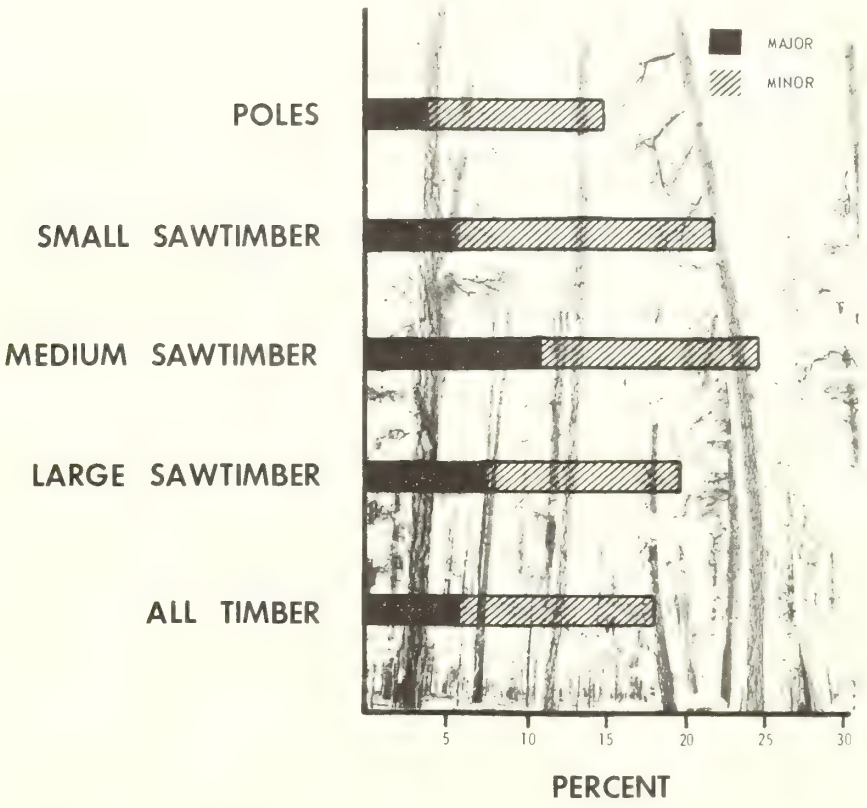

Figure 3.--Percentage of sample trees in four size classes with major or minor sweep (more or less than 1/3 d.b.h. deviation in straightness).

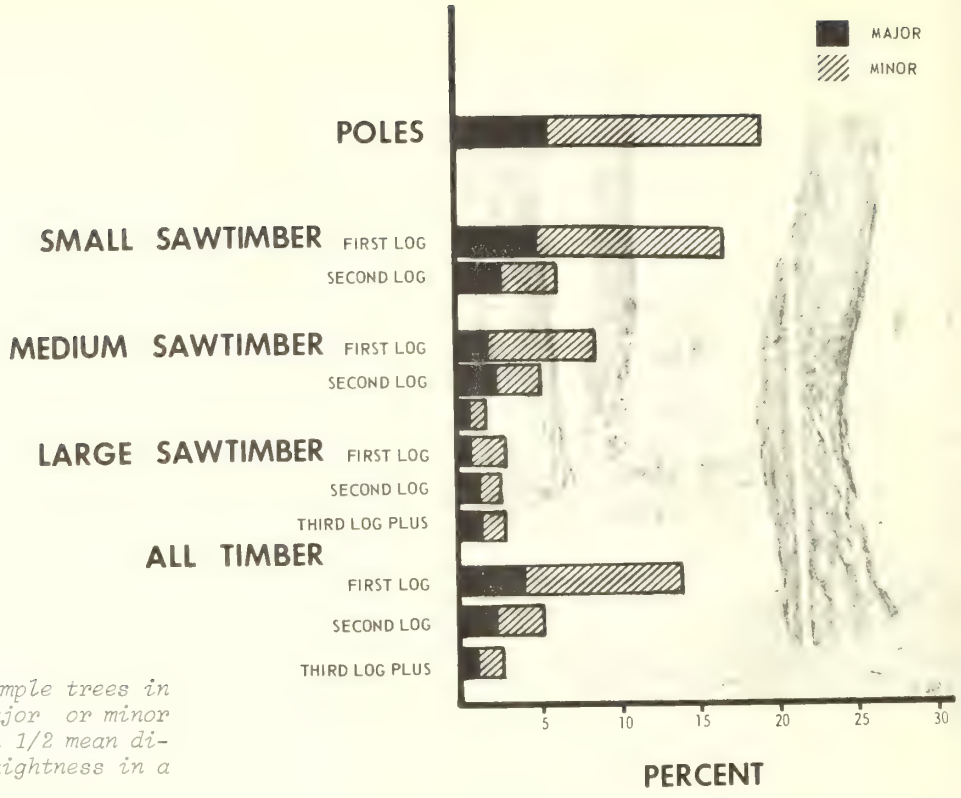

Figure 4.--Percentage of sample trees in four size classes with major or minor crook (more or less than 1/2 mean diameter deviation in straightness in a 5-foot section).

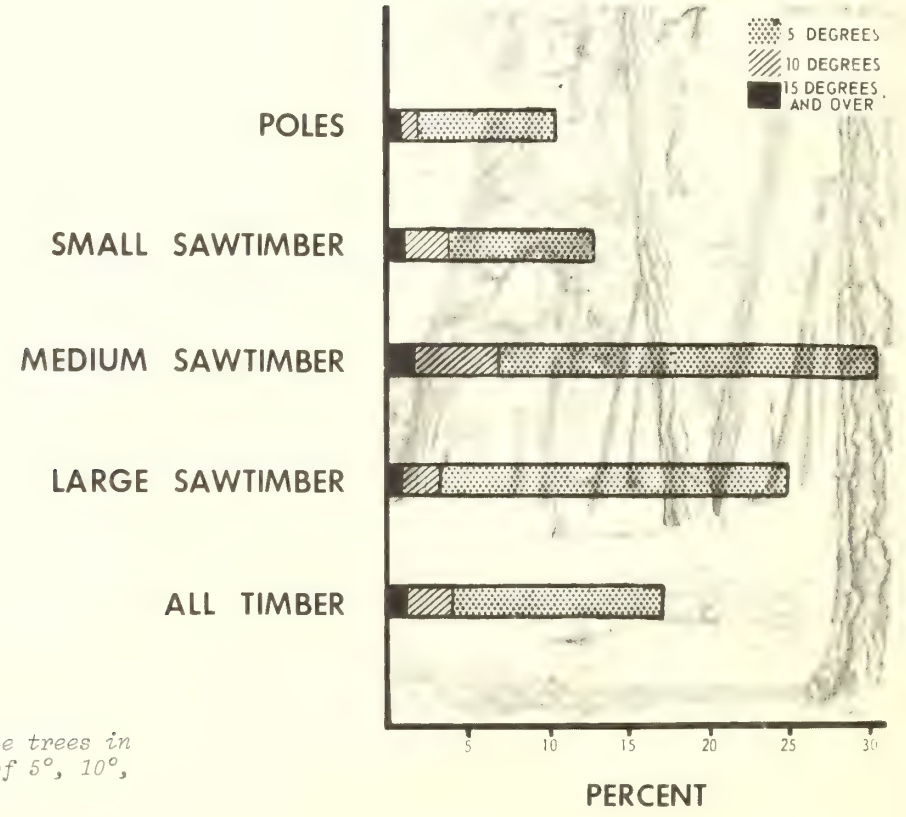

Figure 5.--Percentage of sample trees in four size classes with lean of 5°, 10°, or 15° or more.

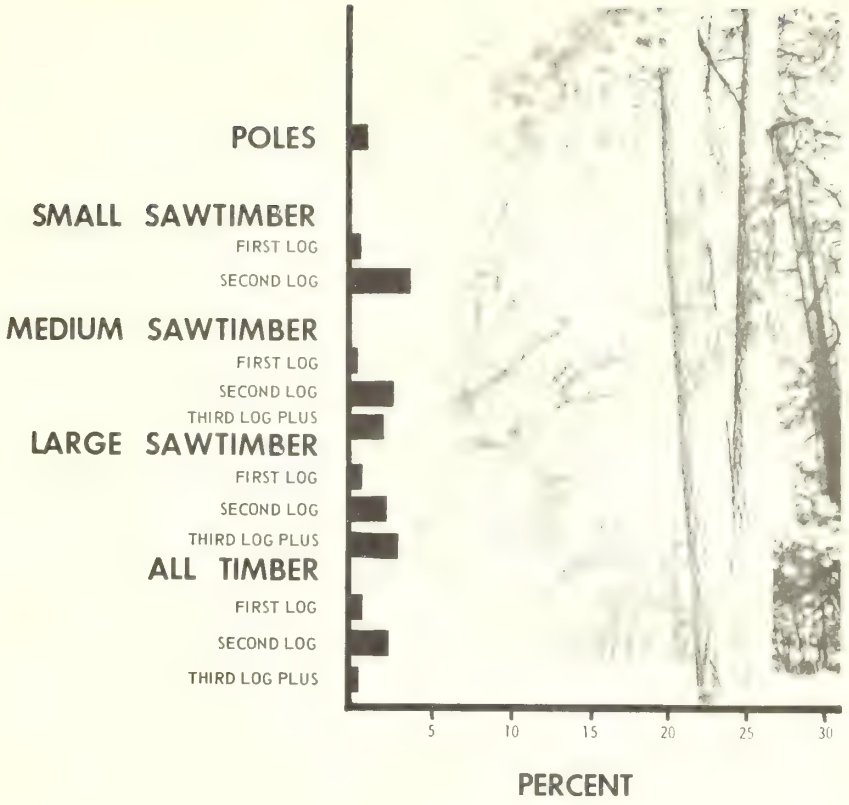

Figure 6.--Percentage of forked sample trees in four size classes.

recognized as secondary grading defects in determining timber quality for various products.

The two most common types of mechanical injuries in standing timber are basal scars, caused primarily by fire, and lightning scars. Basal scars in ponderosa pine are usually confined to the first half-log, whereas lightning scars often affect the entire merchantable stem. Lightning scars constitute a source of serious degrade, even when grown over, and are a major cause of mortality (Myers and Martin 1963, Wadsworth 1943). Dead and broken tops are also mechanical injuries primarily attributable to lightning.

The occurrence of basal and lightning scars, both more prevalent in larger trees, is indicated in figure 7. The occurrence of dead and broken tops in timber on the sample area is shown in figure 8.

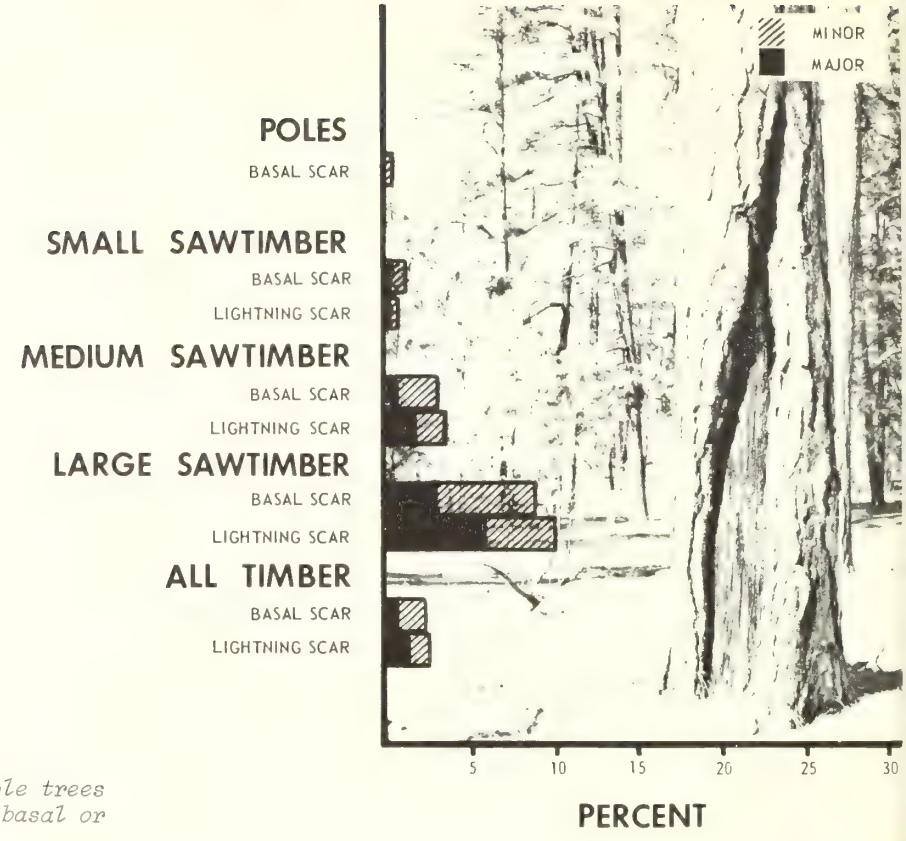

Figure 7.--Percentage of sample trees in four size classes with basal or lightning scars.

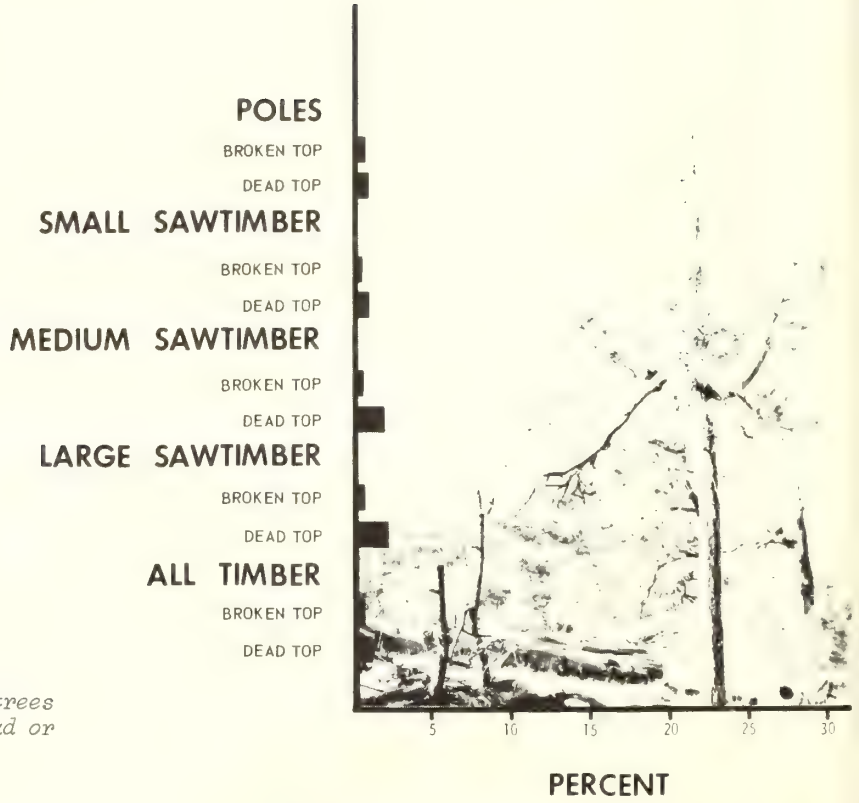

Figure 8.--Percentage of sample trees in four size classes with dead or broken tops.

Log Knot Configurations

The distribution of clear surface area, and the number and size of log knots are perhaps the most important stem features related to quality for most products. A knowledge of clear log surface and knot characteristics is essential to the evaluation of product potential in standing timber. The occurrence of clear 8-foot faces or panels in the butt 16-foot logs of sawtimber trees on the study area is illustrated in figure 9. Although occurrence was recorded for the first 32 feet of merchantable stem, practically all clear faces observed were contained in the first log.

The number and size of log knots in butt 16-foot logs of sawtimber trees are shown in figures 10 and 11, respectively.

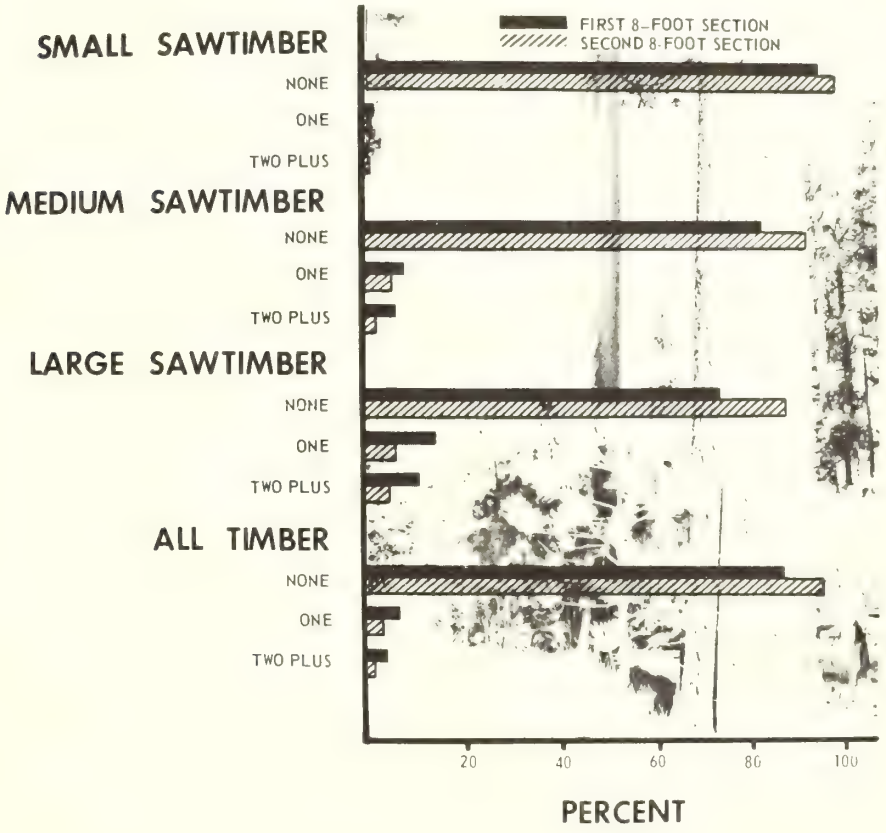

Figure 9.--Percentage of sawtimber stems having none, one, and two or more clear faces in the two lower 8-foot stem sections (first log).

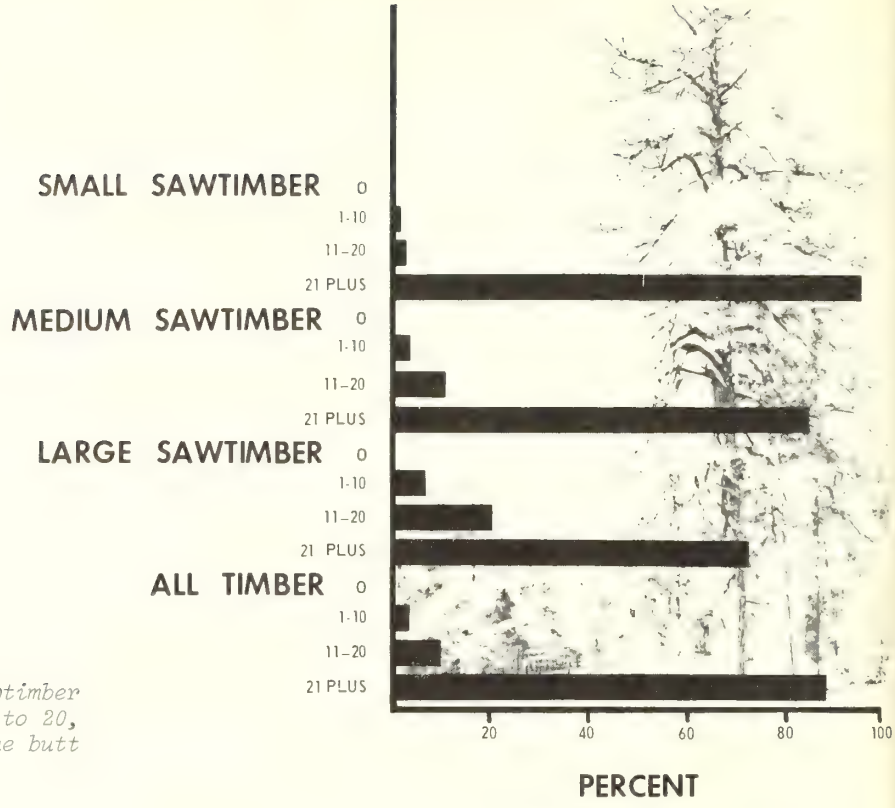

Figure 10.--Percentage of sawtimber stems having 0, 1 to 10, 11 to 20, and 21 or more knots in the butt 16-foot log.

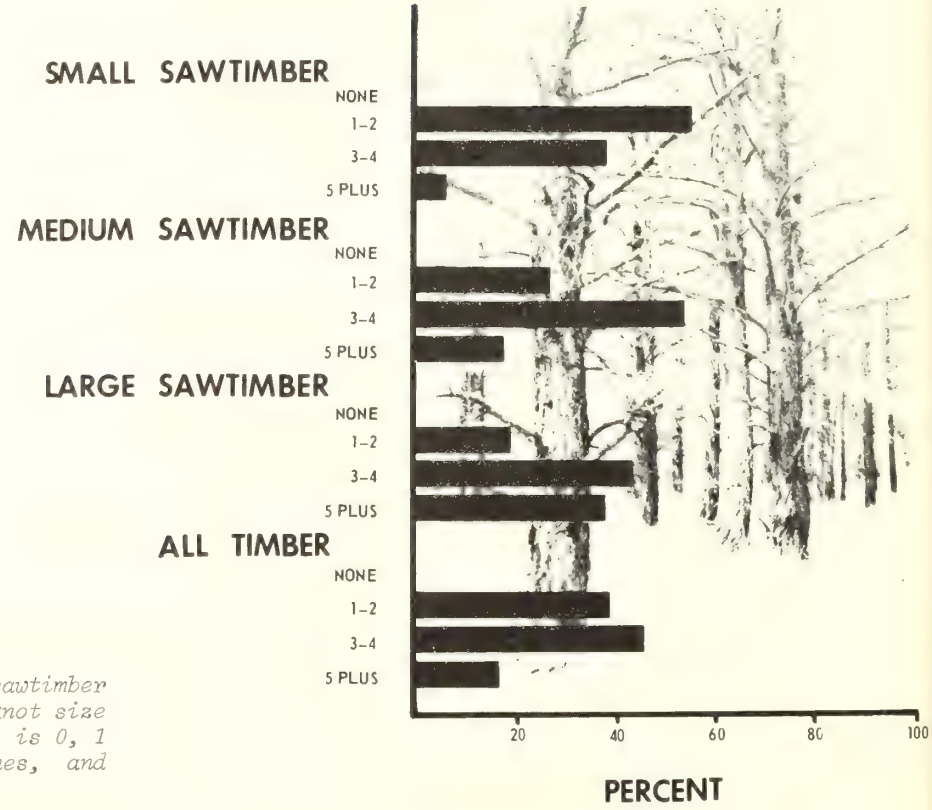

Figure 11.--Percentage of sawtimber stems in which maximum knot size in the butt 16-foot log is 0, 1 to 2 inches, 3 to 4 inches, and 5 inches or greater.

Potential Use of Quality Information

As utilization practices and consumer demands change, and the forest products industry adopts new products and processes, adequate timber utilization planning requires better resource information. Information describing the occurrence of fundamental stem-quality features provides an initial basis for interproduct comparisons and utilization decisions. The suitability of major timber types for a broad range of primary products can be appraised, and the extent to which particular stem defects will reduce product potential can be estimated.

In the Southwest, an increasing dependence upon cutover ponderosa pine necessitates closer examination of the quality of this resource. Data developed during this study are not necessarily representative of all cutover pine in the Southwest but they do indicate the general stem quality to be expected in cutover stands.

In the locale represented by the study area, current activity centers upon lumber (saw logs), commercial poles, and pulpwood. Interest is developing in plywood potential (veneer logs) and in chip or fiber panel product potential. Because the stem-quality features observed and recorded include the major grading and/or limiting criteria applicable to these and other primary products, suitability and range of quality of the resource for any particular product (Ffolliott and Barger 1965) can be reliably estimated. As interest in new products arises, and quality criteria change or develop accordingly, the stem-quality data provide a continuing basis for re-evaluation of resource potential.

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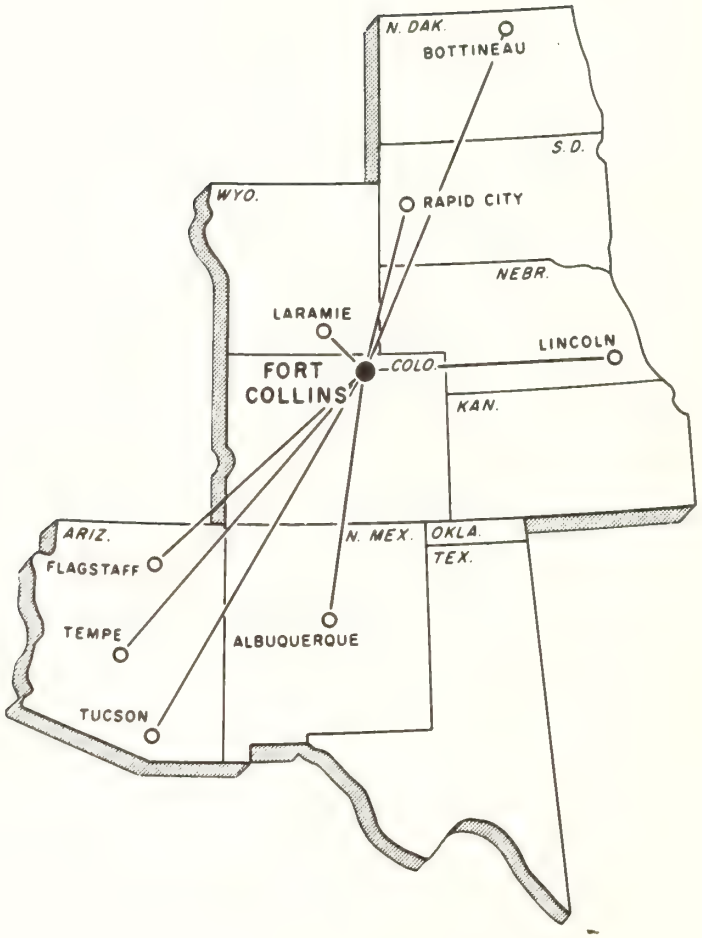
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